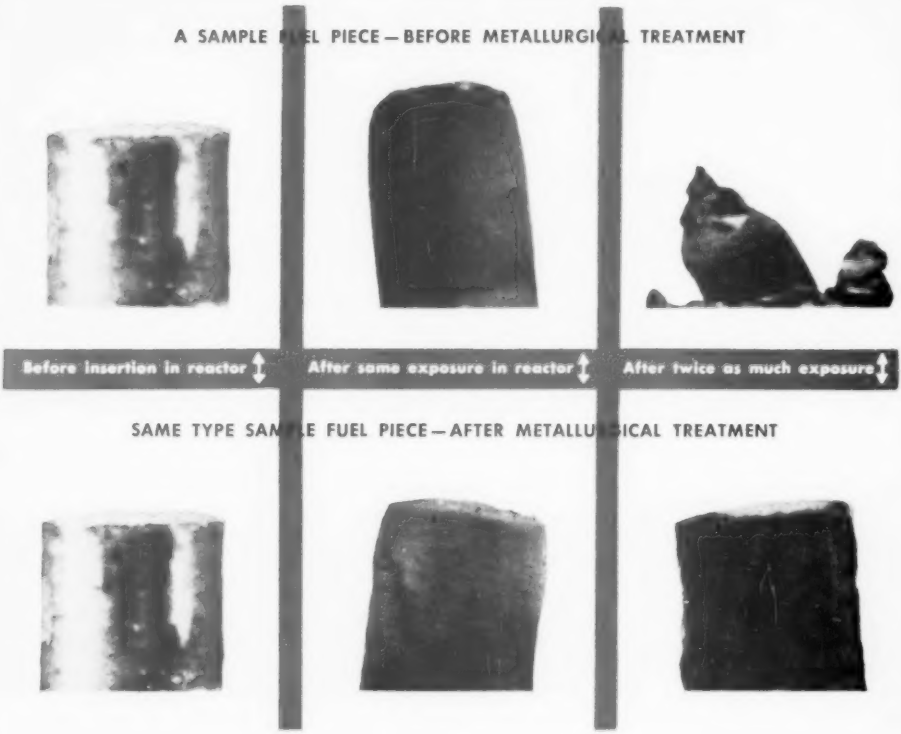
NUCLEONICS

September 1952


A SAMPLE FUEL PIECE—BEFORE METALLURGICAL TREATMENT
Before insertion in reactor
After same exposure in reactor
After twice as much exposure
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PHYSICAL CHANGES DUE TO THE RADIATION IN A REACTOR

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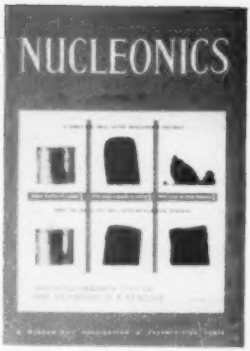

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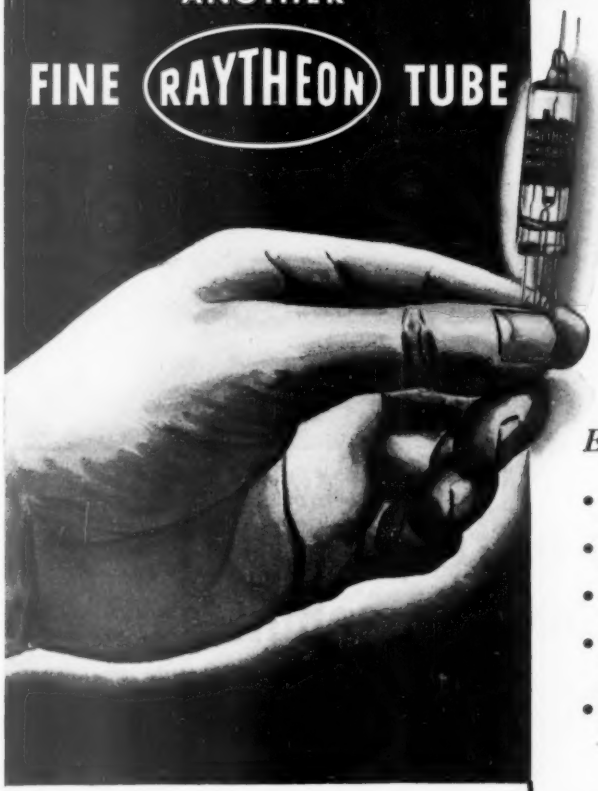

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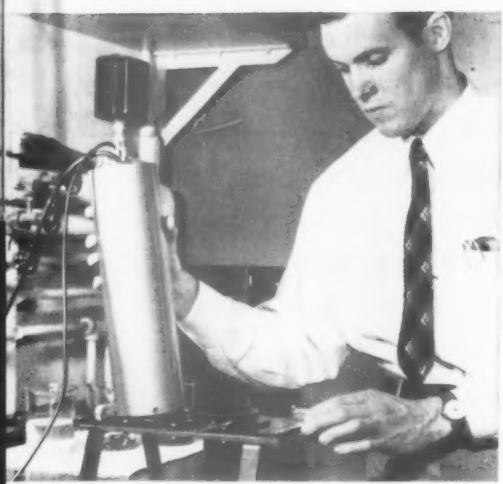

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NUCLEONICS

SEPTEMBER, 1952

Uranium vs Plutonium

NATURAL URANIUM is the lifeblood of the atomic energy program. It is the source of the only two fissionable materials in use today—uranium-235 and plutonium-239. To get the former, the natural uranium is enriched in its 235 isotope; to get the latter, it is transmuted to Pu-239. To date, more money has been spent producing U-235 than Pu-239.

And for the next 5–10 years, this will continue to be the case. Contracts just awarded by the Atomic Energy Commission for new plant construction show that 75% of the nearly $3-billion expansion program money will be used to build gaseous-diffusion uranium separation plants. Most of the remaining 25% will go into new plants at the production reactor centers at Hanford and Savannah River.

Why is all this money being spent and why the emphasis on U-235? Three conclusions are quite obvious: (1) The military has an insatiable desire for fissionable material, (2) The U. S. has access to a more-than-adequate supply of uranium ore, and (3) AEC analysis shows it is wiser to spend its money on U-235 plants rather than those for Pu-239.

WILL U-235 production always outstrip that of Pu-239? Let's first look at what has been done to date.

The first reactor ever to produce plutonium was the Oak Ridge "pilot plant" built in 1943 at a cost of $13-million. After that and during the war, three production reactors were put up at Hanford, and several new ones were erected there after the war. In addition three plants capable of producing plutonium are now being built at Savannah River.

The Hanford wartime installation cost $350-million. By mid-1945 about $1-billion was spent to develop U-235 separation processes.

The present expansion program costs compare as follows: for gaseous diffusion plants—$464-million at Oak Ridge, $459-million at Paducah, and $1.2-billion at a new Ohio plant; for production reactors—$171-million at Savannah River and $411-million at Hanford.

It is apparent that (1) more U-235 could be gotten from the wartime plants within a specified time for the money spent than Pu-239, and (2) this is still the case.

Thus, although considerable experience and know-how in reactor technology have been gained in the past seven or eight years, not enough has been learned which would warrant a shift in favor of plutonium production.

The principal factor involved in the choice of emphasis is the military need. If x pounds of fissionable material must be delivered by some particular date, previously tested and proved methods would naturally be resorted to. There's very little choice. This is also why work on thorium and U-233 has not been pushed.

Thrust into the background are any technical advantages which might accrue from wider use of Pu-239 instead of U-235 in reactors or weapons. For example, in the "neutron economy" in which AEC lives, the three neutrons yielded from Pu-239 fission would give it an advantage over U-235 which yields 2.5 neutrons. In addition, Pu-239 is probably "purer" than U-235, from which nonfissionable U-238 cannot be completely removed.

SURELY means will soon be found to produce plutonium for much less than it now costs. One avenue open towards this end right now is the so-called dual-purpose reactor. Industry wants to build such plants and write off part of the costs by selling to the AEC the plutonium which it would produce. Undoubtedly, numerous independent efforts along such lines will result in reduction of plant costs.

AEC might reverse this procedure, as suggested on p. 14 by Dr. Zinn of Argonne National Laboratory, and reduce the cost of its plutonium by selling or using the power it produces. It appears that such a plan is already being considered (p. 66).

In any event, imaginative thinking will result in the possibility of cheaper plutonium being produced—in addition to cheap nuclear power. But only those new reactors should be built which stem from such creative thinking. Perpetuation of old ideas should be avoided.

—*J.D.L.*

Basic Problems in Central-Station Nuclear Power

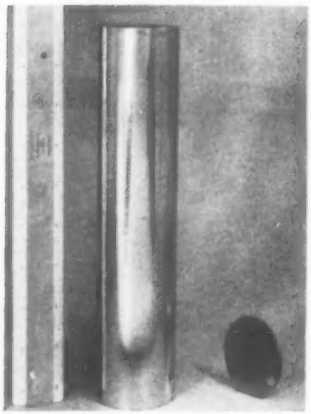

FIG. 1. Twenty-pound cylinder of natural uranium. Disk is amount which is U^{235}

Breeding must be successful before nuclear power can be economically competitive. Here, the head of the principal reactor development center places breeding in perspective and gives the first published details of the Experimental Breeder. He says there is no dearth of power-reactor designs and calls for AEC to build one

By W. H. ZINN
Director, Argonne National Laboratory
Chicago, Illinois

PROPULSION OF submarines and airplanes by engines powered with nuclear energy are projects which currently are in progress under Atomic Energy Commission and Defense Department auspices. Also, numerous estimates have been published of the relative amounts of energy potentially available in minable uranium and in coal, usually with the conclusion that uranium is a *major* potential source of energy. It appears, then, that abundant energy and the means of converting it to practical uses are at hand, and it is entirely excusable if many people assume that central-station electrical power is also virtually here.

If propulsion units for submarines are being built, why cannot larger reactors of the same design or even a number of them together be used as central-station electric power sources? The fact is that they can be so used, but this is improbable because of economic considerations. What is practical, and what can be afforded for a highly specialized military use, may be much too expensive to compete with the conventional sources of electrical energy, water power and coal. Research and development which is required for the military application, however, is pertinent to the central-station power development and has already made its contributions.

The problem is one of economics, but unfortunately the economic side of the subject becomes thoroughly enmeshed in the fundamental design specifications of the central-station nuclear reactor. A detailed examination of this question becomes a jumble of neutrons, dollar signs, and HNO_3.

Sizeable simplifying assumptions must be made if the problem is to be understood easily. These assumptions cannot invalidate the main conclusions, but neither are various more complicated philosophies of reactor operation rejected as being impractical.

There never has been, nor is there now, any dearth of designs of reactors which technically are feasible as producers of electrical power. As the research and development program progresses, it is fair to say that troublesome technical problems are being solved rather more quickly than new ones are being discovered.

What are the principal technical problems confronting the reactor designer? There are four:

1. Choice of heat-transfer systems including the choice of media for carrying the heat generated by the fission process in the reactor to a turbo-generator unit to make electricity. The temperatures required within the reactor which permit the issuing coolant to generate fair quality steam are not too high. As reactor coolants for this application, gas, water under pressure, and liquid metals are feasible.

2. Choice of materials of construction and their stability under the conditions of intense irradiation inside a nuclear reactor. For many reactors, substances such as beryllium, graphite, or zirconium, are used, and these, in conjunction with unconventional coolants, such as liquid metals, require extensive research especially in the subject of corrosion.

3. Chemical processing of the irradiated fuels of the reactor. The primary purpose of this process is to recover fissionable material in usable form, but it must also remove and store

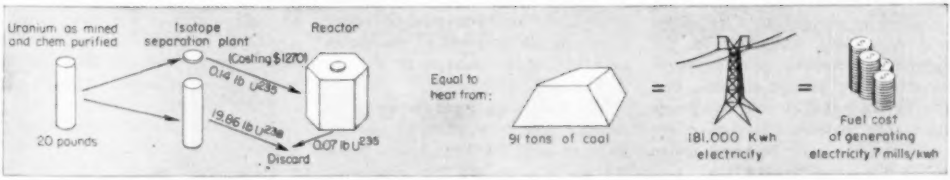

FIG. 2. Estimate of useful energy from nonregenerative reactor

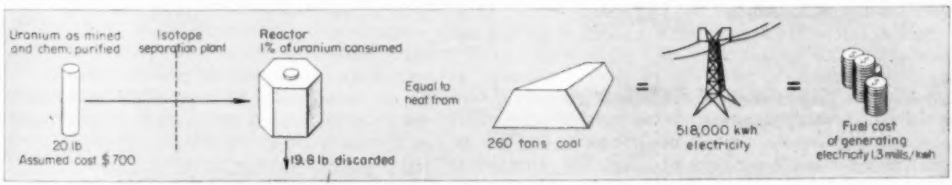

FIG. 3. Estimate of useful energy from regenerative reactor

the highly radioactive fission products. The goal here is to develop efficient and cheap processes.

4. Choice of plant location. So far reactors of large power, with the creation within them of large quantities of radioactive fission products, have all been located on extensive government-owned reservations. Central-station nuclear power plants necessarily will create similar amounts of radioactivity, but it is doubtful that a good solution is to locate each generating station on a large reservation.

There are various methods by means of which nuclear reactors can be used to get the maximum available energy out of our raw material, uranium, and, in discussing some of these, there will be reference to these technical problems. By no means is this paper to be construed as an attempt at a summary of AEC effort in reactor development, but rather it is an indication of some possible paths to be followed in achieving our goal.

The discussion will be based on the silvery-white bar of metal, uranium, which is shown in Fig. 1. This cylinder weighs 20 lbs. Most of it is U^{238} and is nonfissionable. Only 0.7% is the fissionable U^{235}, and this amount is represented by the small disk. Reactors which are fueled with enriched uranium, or U^{235}, have been constructed and operated. The submarine reactors will be such machines.

Figure 2 gives an estimate of the energy which might be gotten in a useful form from the 20-lb cylinder in a reactor which consumes U^{235} and produces heat only. The amount of U^{235} contained in the 20-lb cylinder is 0.14 lb (2.25 ounces), and we assume that the isotopic separation plant can recover all. This, of course, is impossible, but the assumption will not affect our conclusion seriously. The remaining 19.86 lb of U^{238} is discarded as useless waste material, and the 2.25 ounces of U^{235} is placed in the reactor as part of its fuel charge.

It is assumed, however, that it is not possible to run the reactor in such a way that all of the fuel charge can be consumed and the corresponding heat extracted. A number of factors prevent complete consumption: the necessity for maintaining the "critical size" in the reactor; the deleterious effect that the accumulated fission products have on the operation of the reactor; and the difficulty of maintaining the physical characteristics of the fuel itself when a great fraction of it has been converted by fission to entirely different elements. Arbitrarily it is assumed that only one half is actually used and that the rest of the U^{235} is discarded as waste.

The heat generated is equivalent to that obtained by burning 91 tons of coal, or is equivalent to 181,000 kilowatt-hours of electrical energy. It may appear to be a pretty fair exchange in which this small amount of U^{235} is equivalent to 91 tons of coal, but the really important question is—how much does it cost? In a recent speech, L. Hafstad quoted a figure which can be used as a basis for discussion. He said, "The $20 per gram figure is almost certainly low."* At this price the U^{235} costs $1,270, which results in electricity costing seven mills per kwh for fuel alone. Now in conventional coal-burning generating plants, the cost of the fuel, although varying widely from plant to plant, is more nearly 3.5 mills per kwh. Without considering the relative capital investments, it is obvious that the nuclear reactor used in this way is not an economically acceptable process. The cost figure shown here might be quite acceptable for military uses but, at the present time, offers no competition to electricity from coal.

The reactor just discussed is a nonregenerative one because it consumes fissionable material and produces only energy. There are reactors, however, which produce, in addition to heat, fissionable material. The great Hanford plant has as its primary purpose producing plutonium.

Regenerative Reactor

We assume now that the reactor is loaded with both U^{235} and U^{238}. A neutron causes the fission of the U^{235} nucleus which separates into fragments that carry the energy which appears in the reactor as heat. On the average, 2.5 neutrons are also emitted in this fission process. One of these neutrons goes to maintain the chain reaction. What happens to the other 1.5? In the nonregenerative reactor they are lost, either from the outside

*Remarks before American Petroleum Institute, November 15, 1950.

surface or by absorption in the structural or coolant materials. In the regenerative reactor, also called a converter, they are not all lost. One may be captured by a U^{238} nucleus which then undergoes two successive transmutations and becomes plutonium. Thus the original U^{235} atom is replaced by a fissionable Pu^{239} atom, and the amount of fissionable material in the reactor remains constant.

There is still on the average half a neutron available for loss from the surface of the reactor or to be wastefully absorbed. A converter operating in this fashion would apparently not consume any fissionable material but would be generating heat. Basically it is the nonfissionable U^{238} which is consumed.

How difficult is it to make a reactor which would operate in this fashion? It is relatively easy to approximate this performance. The first heavy-water reactor ever built, a research machine, is still operating at Argonne National Laboratory (at its Palos Park location). Since this reactor was designed for use as a research tool, the total power was low, only 300 kw, and thus about $\frac{1}{3}$ gm of U^{235} was consumed per day. But the important point is that, in this reactor, for each atom of U^{235} destroyed, 0.8 of a Pu atom was formed.

Potentially, this increases by a considerable amount the fraction of the total initial uranium which can be fissioned and made to generate power. By the time all of the original U^{235} has been consumed, 80% as much plutonium will have been formed, and then again by the time all of this plutonium has been consumed, an additional amount of plutonium is created, and so on. If we begin with one unit of U^{235}, the total amount fissioned in long operation is given by $1 + 0.8 + (0.8 \times 0.8) + \ldots = 5$. By this regeneration process, the original U^{235} is stretched to five times as much fissionable material, or instead of having the prospect of consuming only 0.7% of the uranium, there is the hope of using 3.5%.

The question naturally arises as to whether this is a practical process. Here we find that the extent to which the regeneration can take place may very well be determined by the radiation damage inflicted on the fuel of the reactor by the intense neutron atmosphere, or by the loss of neutrons to some of the fission products which now have become a large impurity in the fuel. Potentially, we have stretched the available energy by a factor of five, but we may have also acquired an additional cost because before 3.5% of the natural uranium charged into the reactor is consumed, it may be necessary to remove the uranium and chemically process it. Chemical processing of irradiated uranium is, by ordinary standards, expensive, and hence it is highly desirable to do it as infrequently as possible.

Suppose it is possible to charge a heavy-water reactor with natural uranium and leave it in until 1% is consumed. This is considerably less than the 3.5% which is the maximum from which energy can be derived, but suppose that by limiting the consumption to 1%, chemical processing and the resultant expense is avoided.

The economics of the situation is shown in Fig. 3. We start with a 20-lb cylinder of uranium. It is placed in the reactor. One per cent is consumed and the rest is discarded as waste. This much uranium gives energy equivalent to 260 tons of coal, which in turn is equivalent to 518,000 kwh of electricity. What would be the cost of the fuel for this electricity? Unfortunately for the purpose of this discussion, we do not have a cost for refined and purified uranium metal ready to install in a reactor. We do know that the AEC pays $3.50 per pound for uranium in uranium oxide while it is still in the form of ore. Arbitrarily, multiply this by 10. The 20-lb cylinder then costs $700 and the nuclear fuel cost becomes 1.3 mills per kwh.

Thus, use of a regenerative reactor, a converter, has brought the cost of nuclear fuel below the 3.5 mills per kwh which was accepted as the cost of coal in a steam-electric plant. The reduction in cost of fuel makes available extra money to be used as capital for the construction of the nuclear portion of the generating station.

This technique of producing central-station power, using natural uranium must resemble the production plants in which plutonium is made. The difference is that, in the latter, chemical processing must be used to recover the plutonium and that, at least so far, none of the production reactors has attempted to produce electricity from the heat which is generated.

Breeders

A regenerative reactor increases the total supply of energy available and can reduce the cost charged to fuel. The reactor we looked at had a conversion ratio of 80%. But there is the possibility that the conversion ratio could be 100% and that, in addition, more fissionable material could be made than is consumed. This last requires that some fraction of the remaining one-half neutron is also captured in U^{238} to make plutonium. Quite clearly, if this is to be done, great care will have to be taken that neutrons are neither lost from the surface of the reactor nor wastefully absorbed therein. Such a reactor—a breeder—presents some interesting possibilities but also very considerable difficulties.

The first point to note is that as soon as the fissionable material generated exceeds the amount consumed, it is in principle possible to convert all of the uranium to fission products and thereby release 140 times as much

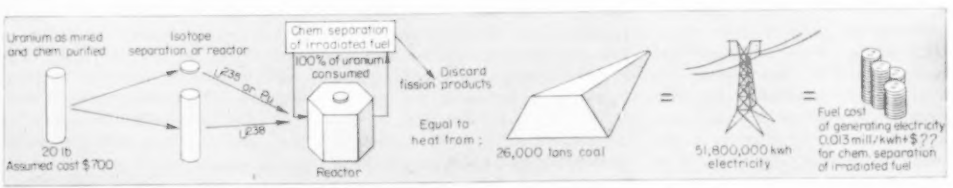

FIG. 4. Estimate of useful energy from breeder reactor

Radiation Damage in a Reactor

THESE two pieces of glass were originally equally clear and transparent. They were placed side by side at the outside edge of the Argonne heavy-water reactor. After a few hours irradiation one was blackened and practically opaque while the other was unchanged. A few years ago all glass so exposed became blackened and opaque, but research carried out at Argonne in conjunction with the glass companies resulted in ways of eliminating this susceptibility to radiation-induced damage.

The photographs on the front cover show radiation-induced changes more directly of concern to a reactor. The top row shows what happened to a fuel piece which contained some fissionable material, and which was exposed to an intense neutron atmosphere in a research reactor. Initially the sample was a smooth cylinder. After irradiation it increased in size, and after still more exposure it actually crumbled. The postirradiation photographs were taken in a hot laboratory and through a thick glass window and do not give very good detail. Just as in the case of glass, however, research leads to techniques by which the radiation effects can be decreased in magnitude. In the bottom row there is a similar fuel piece which has had the benefit of metallurgical treatment of a particular kind, and although radiation damage is still present, it is very considerably ameliorated.

energy as in the case where only all the U^{235} is consumed. The situation is illustrated in Fig. 4. We start with 20 lb of natural uranium. By isotopic separation, or through reactor operation, fissionable material and U^{238} are obtained as separated materials from this 20-lb piece and are charged to the reactor which is assumed to be a breeder. All of the U^{238} is consumed and therefore heat equal to that from 26,000 tons of coal is generated, which produces electrical energy amounting to 51,800,000 kwh.

It is only through breeding that presently estimated resources of nuclear fuels can make a really significant addition to the world's energy resources. So far the discussion has involved U^{235}, plutonium, and U^{238}, but the process from the nuclear standpoint works also for the fissionable U^{233} and thorium, so that for this reactor the world's thorium supply can be included as an energy resource.

It has been frequently asserted that the fuel cost for nuclear power plants would be zero or negligible. In the previous illustrations this hardly has been so, but if a value of $700 is assigned to the 20-lb piece of uranium, the cost is only 0.013 mills per kwh.

To believe that breeding necessarily brings the fuel cost down to a negligible amount is a hasty conclusion. It is certain that in converting all of the uranium to fission products, there will be a number of chemical processing cycles.

In a breeder the fuel which is charged into the reactor will have to be removed, after a bit, chemically repurified, and replaced. This will be costly but should not be so costly that the fuel charge for a breeder will become of principal significance. For instance, if the cost of the uranium as fuel is raised by a factor of ten by the chemical processing, the cost of fuel for the breeder is still negligible. If the cost of the uranium as fuel is raised by a factor of 100—to $3,500 per pound—then the cost contributed by the fuel to the electricity produced is no longer negligible and in the economic sense the advantage of the breeder has become borderline.

Extensive research and development on processes for the recovery of unused fuel from reirradiated materials is being done. We can look forward to a steady decrease in cost as experience in this very new and very challenging area is accumulated.

It is easy to recognize that for any type of operation of a reactor there might be economies and other advantages if the fuel were used in a fluid form. This is the homogeneous-reactor approach and has a very strong appeal because chemical processing may be simplified and also because radiation damage effects, while not absent, may have much less troublesome characteristics. Oak Ridge National Laboratory is actively engaged in exploring such possibilities of reactor operation.

Experimental Breeder Reactor

Although chemical processing is a central point in the economic feasibility of operating power breeder reactors, we cannot lose sight of the fact that we do not know that we can operate a reactor in which the necessary economy of neutrons exists. The margin available is small, and it is for this reason that experimental machines in which the appropriate measurements can be made have been built. Perhaps more such experimental devices will be necessary before we are on sure ground as to the fundamental feasibility of the process.

In December, 1951, the first machine designed to give over-all information on the breeding process was put into operation by the University of Chicago's

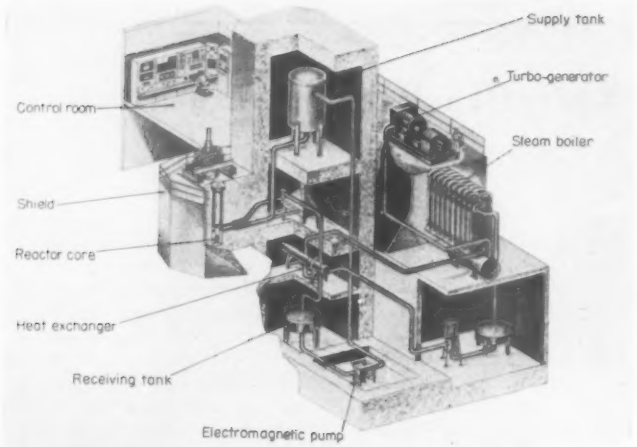

FIG. 5. Experimental breeder reactor and steam-electric generator

FIG. 6. Experimental breeder reactor

Argonne National Laboratory at the National Reactor Testing Station, Arco, Idaho.

Figure 5 is a simplified drawing of the reactor and its cooling system. Since it is to perform as a breeder, great care must be used not to waste neutrons. There is no moderator, and the reaction takes place with fast neutrons. The materials of construction are nearly all metal and fissionable material.

The coolant for the reactor is also a metal, an alloy of sodium and potassium. This coolant was chosen because it does not moderate neutrons appreciably and it does have rather fine characteristics as a heat-transfer medium. For instance it is liquid at room temperatures but boils at 1,500° F. Unfortunately it is also chemically active and must be kept away from air since it burns vigorously if exposed.

The reactor core has a very small volume and can hardly be seen on the scale of this drawing. The general arrangement of the reactor itself is shown in Fig. 6. Details and matters of security interest are not given but the size of the core is indicated as being about that of a football.

The sodium-potassium alloy flows first through a U^{238} blanket surrounding the core and then through the core. Most of the heat is generated in the core, but, since there is a relatively small amount of U^{235} in the core, most of the neutrons which must be captured by U^{238} to make plutonium will be captured in the blanket. Thus most of the fissionable material is generated in the blanket.

The coolant, which is now hot, both thermally and radioactively, flows through a heat exchanger to a receiver tank. From the receiver tank it is pumped by an electromagnetic pump to the elevated storage tank from which it flows again to the reactor. The tanks, the pump, and the heat exchanger are in concrete-walled cells to shield against radiation.

To limit the volume which must be shielded, the heat is removed from the heat exchanger by another circuit of sodium-potassium alloy which is not radioactive since the two streams of sodium-potassium alloy are separated by the tubes of the heat exchanger and there is no transfer of radioactivity from one to the other. This secondary system of hot liquid metal flows to a steam boiler and superheater. Here again there is a piece of equipment of unique design because hot Na-K alloy and water are in the same apparatus.

Since sodium and water may react explosively if they come in contact, the steam boiler does not resemble the conventional type at all. In many ways it is simpler, since there is no problem of the corrosive properties of hot gases from burning coal. The steam is conducted to a turbogenerator unit, condenser, and back to the boiler.

The volume in which the heat is generated is very small compared to the volume of the heat conversion equipment which is outside of the reactor. This is generally true of reactor installations and will be particularly true of a breeder reactor, and consequently the cost of a reactor installation is very much determined by the equipment exterior to the chain-reacting unit.

Table 1 lists some of the operating characteristics of the Experimental Breeder Reactor, which, as far as we know, generated the first electricity from atomic power. The generator output can operate all the facilities of the reactor and its building.

The neutron flux for this reactor is 6.5×10^{14} n/in^2/sec. This is higher than for any other reactor for which information is available. Behavior of the core materials subjected to this flux is of prime importance.

The nuclear chain reaction has a unique feature in that the density of energy generation is determined entirely by the ability to cool, whereas in more conventional sources of heat it may be determined by the ability to pump in fuel.

In the Experimental Breeder Reactor, energy is released at the rate of 4 kw for each cubic inch of the core. How does this compare with other heat sources? Table 2 shows that a high-pressure, oil-fired naval boiler gives only $\frac{1}{7}$ as much. For a central-station steam boiler it is still smaller, but of course in that case there is no great premium on conserving space. For the combustion chamber of a turbojet engine it is $\frac{1}{5}$ as much, but a V-2 rocket has a power density seven

times greater. However, in the combustion chamber of a rocket, all of the fuel is consumed in some seconds, whereas a reactor runs on steadily day after day.

In a large reactor, such as the Brookhaven research reactor, the power density is also very much less than in the breeder. This illustrates one difference between a reactor operating on fast neutrons and one in which the neutrons are moderated. This large difference in the density of energy generation is characteristic of the two types of reactors.

There is one more aspect of the operation of a breeder which requires comment. In principle, it is possible to assign a charge of refined fissionable material to the reactor and then, at some subsequent time, the interest, that is the extra material manufactured, can be subtracted from the reactor. After enough of such so-called interest has been accumulated, presumably another breeder reactor could be started up, and in this way eventually a large number of nuclear power plants could be realized without calling for the diversion of fissionable material from our stockpile. Suppose the reactor, in consuming its fuel charge, regenerates itself and gives 10% extra. If fissionable-material stocks are to be accumulated in this way, this bonus should be received at frequent intervals. This means a high consumption rate of the reactor fuel charge and accounts for the concern with very efficient coolants and the high density of energy release.

Economic Feasibility

Thus there are ways of realizing the large potential energy in uranium and also thorium but we have not come to any conclusion regarding the economic feasibility of nuclear fuels. Several additional facts are required.

First, the nuclear reactor replaces only a part of the steam generating plant and affects not at all the electrical distribution system. Figure 7* illustrates the part which might be replaced. At the top is a schematic diagram of a large coal-burning steam-electric installation. The coal hopper and the steam boiler would be removed and replaced by a nuclear reactor and a different kind of steam boiler. Below for illustration, to the same scale, the Brookhaven reactor, which has the largest dimensions of any reactor for which the dimensions have been released, is shown as well as the necessary steam boiler. Physically, there is no reason to suppose that the reactor will bring about much change in the size of the generating station.

The second fact is that for coal-burning generating plants now being built, an average capital cost of $200 per kilowatt of capability can be assumed. Of this, close to 50% goes into the parts replaced by the reactor.

An indication of the economic situation is summarized in Table 3. Available to reactor construction, as a result of eliminating coal handling and the boiler, there is $100 per kilowatt of capability. To this must be added the saving due to the use of nuclear fuel rather than coal.

For the first type of operation discussed, where separated U^{235} is consumed, it is clear that even a capital-cost-free plant does not produce electricity as cheaply as a coal-burning plant. For the second type of operation, where there is conversion to either plutonium or U^{233}, and in which 1% of the nuclear fuel is assumed to be consumed, it is seen that the permissible cost of the nuclear installation is $45,600,000. The total nuclear steam-electric plant must not exceed $65,600,000.

For the third type of operation, in which breeding is assumed, it is seen that the permissible amount for the nuclear installation has risen to $60,800,000, and that the total plant must be built for $80,800,000. The margin of the breeder reactor over the converter is actually not as great as shown here for, as has been indicated earlier, there will be a requirement for chemical processing.

Cost-wise, there may be no sizeable differential between these methods of reactor operation; this permits the choice of plant to be determined by other factors such as the raw material required to support the reactor.

The raw material requirement is indicated in the last column of Table 3. The cost of constructing large reactors is not public information, but a comparison with the research reactors for which costs have been published leads one to believe that these sums may be insufficient. None of the comparison reactors is large in terms of energy release, but large capability reactors offer more hope in being competitive because many savings can be realized by increasing the size of rather than duplicating equipment.

The large capital investment apparently required for a nuclear-fuel steam-electric plant is the central difficulty. No amount of paper analysis can substitute for actual experience or remove the economic question mark. It may be that the scheme of having private power companies erect their own plants and then selling plutonium to the government will produce the foundation on which a nuclear-fueled electrical power industry can be based. But the Government is deeply involved since it must guarantee a price for plutonium which will protect the companies from financial loss or else the plants will not be built.

The AEC itself is the single largest user of electric power in this country. It does have extensive reservations on which large-capacity reactors are operated and therefore the unresolved problems of choice of plant location do not apply. If AEC were to undertake to construct and operate power

TABLE 1—Some Operating Characteristics of Experimental Breeder

Core volume	a regulation football
Na-K alloy temperature at exit	660° F
Steam pressure at turbine	400 psi
Generator capacity	250 kw
Neutron flux	6.5×10^{14} n/in²/sec
Power density	4.0 kw/in³

TABLE 2—Comparison of Power Density of Heat Sources

Source	*Rate of release* ($BTU/ft^3/hr \times 10^6$)	*Power density* (kw/in^3)
High-pressure naval boiler	350	0.6
Turbo-jet-engine combustion chamber	400	0.7
V-2 rocket	17,000	29
Brookhaven reactor	0.6	0.001
Experimental breeder reactor	2,350	4

* From a paper presented by Philip Sporn and S. N. Fiola to the American Society of Mechanical Engineers, Nov., 1951.

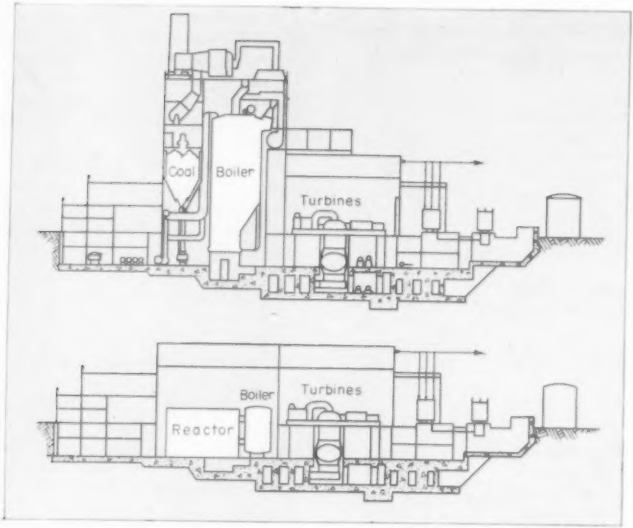

FIG. 7. Relative sizes of nuclear and coal steam-electric plants; Brookhaven reactor is shown to scale in bottom drawing

TABLE 3 — Economics of Reactor Operation for Nuclear Steam-Electric Plant

	Investment credit per kw of capacity		*Installation with electric capacity of 2 × 10⁵ kw*		
Type of reactor operation	*For part of coal plant displaced ($)*	*For fuel savings (Capitalized at 12%) ($)*	*Permitted cost of reactor and boiler ($-million)*	*Permitted total cost of nuclear steam-electric plant ($-million)*	*Annual uranium fuel requirement (tons)*
Consumes separated U^{235}, regenerates no fuel	100	(−204)	—	—	77
Converter, 1% of uranium consumed, no allowance for chemical processing	100	128	45.6	65.6	27
Breeder, fuel cost including chemical processing considered negligible	100	204	60.8	80.8	0.27

plants on these reservations with public funds, this would place the Government in competition with the private utility companies and we have other examples where this leads to unending debate and very strong opposing opinions as to whether the power production is or is not being subsidized at the public expense. Reactors constructed by the Commission on present reservations would not necessarily bring such criticism if certain restrictions were incorporated in the initial plan. These would be:

1. The requirement that the Commission construct only power plants which are of a regenerative type so that fissionable material which is now urgently needed for our military stockpile is also produced. This protects the public against paying for expensive power if it turns out to be expensive, since there is no question that the military value of the fuel recovered could provide a substantial subsidy.

2. In any particular location, amounts of electric power exceeding those which are purchased by the Commission from the surrounding utility network should not be produced. Since the Commission is a very large user of electricity, this is an easy condition to meet, but it does place a limitation on the competition the Government-owned utility plant gives to the privately owned and previously established utility networks. The electricity generated from nuclear fuels could not seriously compete with the electricity produced privately as long as national needs keep increasing at the present rate of 10% a year.

3. The nuclear-fueled power plant is to be designed and operated in such a way that clear-cut cost figures for the production of the electrical power can be obtained. These cost figures should be continuously available to the private utility companies. Thus, if this enterprise were to show that nuclear-fueled electrical power has reached the stage where it is cost-wise comparable with other fuels, the utility companies would have early and firsthand information.

The alternative to plans of this general character is to permit a much longer time for expensive development and experience and to run the risk of seeing central-station electrical power developed in countries where the lack of conventional energy resources makes the need much greater than here.

Although from this analysis one can by no means conclude that economic nuclear power could be achieved now, it is also quite definite that there is no reason to be pessimistic about the ultimate practicability. Philip Sporn, president of the American Gas and Electric Company, and also chairman of the Ad Hoc Advisory Committee on Cooperation between the Electric Power Industry and AEC, has said: "Nuclear power has a truly robust prospect. But it is a prospect only."*

The reactor research and development program of AEC, whether motivated by military needs or the "robust prospect," is making substantial progress in solving technical problems. Vast quantities of competitively priced nuclear power will result. It may not be much cheaper power, but this energy source should become available for our expanding needs.

* Annual Report, American Gas and Electric Company, for 1951.

* * *

This article is based on a talk given to the administrative staff of Argonne National Laboratory.

Scintillation Counting Techniques

TABLE 1—Fluorescence of Substances as Crystals and in Solution

	Intensity relative to anthracene in solid form (per cent)		
		Xylene solutions	
	Powder	*Maximum*	*Extrapolated*
Organic Substances			
Anthracene	100	6	12
Anthranilic Acid	15	15	22
Carbazole	33	12	20
Chrysene	35	~0	..
Dichloroanthracene	4	~13	..
Diphenyl	24	2	..
1,4 Diphenylbutadiene	67	12	19
Diphenylhexatriene	4	14	35
Diphenylhexatriene	4	21*	48
Dihydrocollidine	26	~0	..
Durene	54	12*	14
Fluoranthene	31	8	8
Fluorene	45	15	22
Methyl Anthranilic Acid	18	13	20
Methyl *p*-Aminobenzoate	2	6	15
Naphthacene	~1	~0	..
Naphthalene	15	3	..
α-Naphthylamine	5	17	26
β-Naphthyl Ethyl Ether	56	14	..
β-Naphthyl Methyl Ether	56	14	..
Phenanthrene	46	~0	..
Phenyl α-naphthylamine	27	23	33
Pyrene	52	9	9
Quaterphenyl	85	~20	..
Stilbene	73	4	4
m-Terphenyl	25	20	..
o-Terphenyl	2	~0	..
p-Terphenyl	55	48	60
Inorganic Substances			
CsBr (Tl $\frac{1}{2}$%)	210	..	..
CsI (Tl)	145	..	..
KI (Tl)	83	..	..
LiF (AgCl 100 ppm)	5	..	..
NaCl (AgCl 1%)	115	..	..
NaI (Tl)	~200†	..	..
ZnS (Type D)	200	..	..

* Phenylcyclohexane used as solvent.

† Crystal was not powdered—compared to anthracene crystal not powdered.

Merits of the counting, integrated intensity, and storage methods for obtaining dose and dose rate of high-energy radiation are discussed. Intensities of 10^{-6}r/hr can be measured by the first two methods; the third can indicate as little as 10^{-3}r even after a considerable lapse of time

By HARTMUT KALLMANN, MILTON FURST, and MIRIAM SIDRAN

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Investigation of high-energy radiation can be carried out with the aid of luminous materials by three different methods: (1) the counting method; (2) the integrated-intensity method; and (3) the storage method. The first two methods determine the dose rate whereas the third method measures the total dose received by the exposed material.

The first two methods require substances with very large luminous efficiencies. But with such measurements the usable volume of the material is limited by the dimensions of the light-sensitive surface of the photomultiplier, and the efficiency per unit volume is of greatest significance. However, it is customary to determine the physical efficiencies for equal amounts of absorbed energy. For very penetrating gamma radiation, this absorbed-energy efficiency is equivalent to the efficiency per unit mass since equal masses absorb nearly equal energy in this energy range. The relative fluorescent efficiencies given in Table 1 for different powders and solutions are corrected for equal masses. To compare the usefulness of these substances for the first two methods, the values in Table 1 should be multiplied by the density of the material.

The values were obtained by measuring the fluorescent light output produced by a 1-millicurie radium source using an integrated-intensity method with a 1P28 photomultiplier (*1*). For solid material measurement thin powdered layers were used; it has been found that the light output of large single crystals often depends to a considerable extent on the crystal growing technique.

The values listed for the solutions were obtained by determining the light output of a certain amount of solution relative to the light output of an equal mass of crystal anthracene. The second column gives solution efficiencies at optimum concentration. This maximum light output has to be considered when comparing the efficiencies of different substances since the light emission of a solution increases with concentration, goes through a maximum, and declines at large concentrations. For physical purposes, however, it is often valuable to determine the light output that would be obtained without the concentration quenching. These extrapolated values for some solutions are given in the third column of Table 1 (*2*).

The values of Table 1 still do not represent the true relative physical light efficiencies since a correction

factor for the difference in the spectral distribution of the emitted light has to be applied. For most of the materials these factors do not differ greatly from one since all of the substances listed possess an emission spectrum lying mostly between the near ultraviolet and the blue.

It is noteworthy that the best known solid organic material (anthracene) is about half as good in powder form as some of the well-known inorganic materials of the zinc sulfide type. The best fluorescent materials found were cesium bromide and the often-used sodium iodide, both activated with thallium. Because of its higher density cesium bromide is the substance most suitable for use with the integrated-intensity method. (The inorganic crystals used were kindly furnished by the Harshaw Chemical Company.)

For scintillation counting, the overall physical efficiencies are not the only important factors. An additional requirement is that most of the emitted light be given off in a period of time of certainly less than a microsecond. For all efficient organic compounds so far studied, this requirement seems to be fulfilled. In all the cases tested the observed relative peak heights of the light flashes are fairly proportional to the values given in Table 1. With inorganic substances, only sodium and potassium iodide give off most of their light in a relatively short time; most of the other substances give smaller maximum peak-height values than expected from Table 1 (if the counting measurements were carried out with a circuit decay time of less than a microsecond). It is likely that the differences between the relative values of Table 1 and those of the maximum peak heights are due to differences in the emission time of the fluorescent light (*3*). It seems that for some inorganic substances a considerable portion of the light is emitted during a period of time much greater than a microsecond after the energizing by the high-energy quantum has taken place.

There is another important difference between the counting and the integrated-intensity method. Counting gives the number of quanta absorbed per second by the fluorescent substance but does not give the total amount of energy absorbed even if the response of the scintillating material is independent of the frequency (energy) of the incident radiation. The reason for this is that the number of counts per unit time is proportional to $\int dE/h\nu$ and not to $\int dE$ which gives the total energy absorbed per unit time; here dE is the energy absorbed per unit time in the interval $d\nu$.

The integrated-intensity method, however, measures the total light energy emitted by the fluorescent substances when energized by high-energy radiation. If the physical light efficiency of the material used is independent of the frequency, the values measured by this method would be proportional to the total absorbed energy per unit time. Since the light efficiency of the organic crystals shows no large frequency dependence down to rather small values of quanta energies of 100 kev (*4*), this method gives values which are fairly proportional to the roentgen dose rate of the incident radiation.

Roentgen Dose Rates

The possibility of getting some direct information about the roentgen rate value makes it interesting to compare the sensitivities of the counting and integrated-intensity methods. The dose rate of 1 μr/hr (equivalent to approximately a microcurie radium source in one meter distance) normally gives a counting rate of the order of 100 cpm with a 2-cm cubical sodium iodide crystal. With a specially constructed integrated-intensity meter that measures all the current induced in the photomultiplier by the light emitted from the fluorescent material, a deflection of 50 divisions is obtained with 5×10^{-4} r/hr. Since the dark current is 3 divisions, a dose rate of 10^{-6} r/hr can just be detected. These measurements were made with a 1-cm cubical sodium iodide crystal 15 millimeters away from the window of a 1P28 photomultiplier. With a larger crystal closer to the window, still higher deflections could be obtained.

Some measurements with this arrangement are described in Table 2. With an anthracene crystal of the same volume, smaller deflections would be obtained but the deflection would be proportional to the dose rate even with a nonuniform frequency distribution. These measurements show that the integrated-intensity meter is also suitable for detecting very small radiation intensities. Its great advantage is that it needs no scaler equipment but only a small amplification (less than 10) and a crystal diode.

Storage Method

The third method makes use of the well-known method of energy storage in phosphors for determining total doses (*5*). A luminescent substance is irradiated by high-energy radiation for a certain period of time, receiving a definite dose. If the substance used is a so-called storage-type phosphor, a certain amount of the absorbed energy is stored in the substance for a considerable length of time and can be released in the form of light (stimulated light) by irradiation with visible or infrared light. This stimulated light has mostly a shorter wavelength than the stimulating light.

A considerable number of storage phosphors have been tested for their usefulness with high-energy radiation; some available phosphors are suitable for this type of work. The best is a sodium chloride phosphor activated with 1% silver chloride (supplied by the courtesy of the Harshaw Chemical Company). Its stimulated light output is nearly proportional to applied gamma-ray doses from 10 mr to 10,000 r. Only with greater doses does the

TABLE 2—Integrated Response of NaI (Tl) Crystal to Different Gamma-ray Sources

Source	*Crystal*	*Mass (gm)*	*Distance*		*Deflection (arbitrary units)*
			Crystal to photomultiplier (mm)	*Source to crystal (cm)*	
Radium (1 mc)	NaI (Tl)	8.2	15	100	124
Cobalt-60 (8.2×10^{-4} mc)	NaI (Tl)	8.2	15	4	54

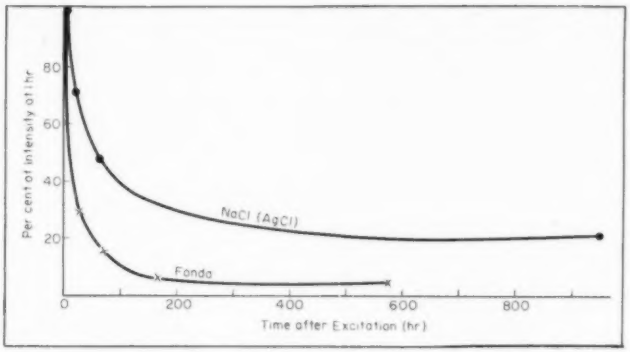
response of the phosphor become saturated. This phosphor has the capability of being used again and again. An extended check of these crystals under weak and strong gamma-ray and electron bombardment clearly shows that they do not deteriorate even if they receive very high total doses of several million roentgens.

Other storage-type phosphors are especially useful for low gamma-ray doses from 1 mr to 1 r. Some of the Fonda phosphors show a response to stimulation that is fairly proportional to the previously applied dose in this range. With a Fonda phosphor supplied by the New Jersey Zinc Company, it was possible to detect a dose of 1 mr one day after the dose was applied.

The experimental procedure is as follows: The sample first receives the gamma-ray dose. Sometime later, it is placed in the special integrated-intensity arrangement used with the second method; in this apparatus infrared irradiation is applied which releases the stored energy as visible light. This visible stimulated light is measured simultaneously with application of the infrared and is fairly proportional to the given dose. With the activated sodium chloride crystal, this procedure is even simpler once these crystals are excited with gamma radiation. They receive a short irradiation with visible or near-ultraviolet light. This irradiation releases the stored energy and gives rise to an emission mostly in the ultraviolet range, but in this case the stimulated intensity need not be determined simultaneously with the stimulation because the crystal shows a definite slow phosphorescence after stimulation. Thus it is possible to stimulate the crystal and to measure the stimulated intensity some time after stimulation. Here too it was found that these stimulated intensities are proportional to the previously applied dose.

Storage-Use Precautions

Precautions have to be taken when these substances are used as dosimeters. For a low dose, side effects can occur which depend on the way in which the stored energy from a previous exposure has been removed. A large series of experiments has been carried through to find a procedure for quenching these powders in a way which makes them usable even for low



DECAY of stored energy without stimulation

doses. Success was obtained with some Fonda phosphors for measuring doses down to 1 mr. These Fonda phosphors store a relatively large amount of the absorbed gamma radiation and transform it into light when stimulated, but they are not the most sensitive phosphors in this respect. The well-known Standard VII and B-1 phosphors are still better, but their residual effects at low excitation are so strong that they are not usable with low doses.

Another difficulty is that the energy stored in these phosphors decays slowly with time even without being stimulated. Thus the readings obtained after stimulation also depend on the time lapse between excitation and stimulation. As shown in the illustration, however, for some of these phosphors the decay curve of the stored energy becomes quite flat if the reading is taken hours after the excitation. If the time after excitation is known, one can determine the dose by finding the loss of stored energy from the decay curve. It is seen from the curve that the rate of decay of the stored energy becomes very small as the time interval between excitation and stimulation increases.

The storage method may be useful also for dose-rate measurements in some special cases where the sensitive instruments used with the counting and integrated-intensity methods cannot be brought close enough either to the source of high-energy radiation or to the region where the radiation is to be determined.

* * *

This article is based on a paper presented by H. Kallmann before the Radiation Division, American Industrial Hygiene Association, Cincinnati, Ohio, April 24, 1952. The work is supported by the Signal Corps Engineering Laboratory, Fort Monmouth, N. J., under contract DA 36-039 sc-5487.

BIBLIOGRAPHY

1. H. Kallmann, M. Furst, *Phys. Rev.* **79,** 857 (1950)
2. M. Furst, H. Kallmann *Phys. Rev.* **85,** 816 (1952)
3. L. Bittman, M. Furst, H. Kallmann, *Phys. Rev.* **87,** 83 (1952)
4. C. J. Taylor, W. K. Jentschke, M. E. Remely, F. S. Eby, P. G. Kruger, *Phys. Rev.* **84,** 1034 (1951)
5. M. Furst, H. Kallmann, *Phys. Rev.* **82,** 964, **83,** 674 (1951)

More AIHA Articles to Appear

This article and the ones on pages 18-27 are based on papers from the Radiation Division meeting of the American Industrial Hygiene Association. The following papers will also be published:

Engineering Studies of Filter-Bed Efficiency for Treatment of Radioactive Waste, by Lee Gemmell

Absorption of Alpha Particles by Filter Paper; Its Effects on Counting Air Dust Samples, by John Alercio and John Harley

Cyclotron Radiation Hazards, by Herbert Mermagen

Relation of Photographic Film Characteristics to X- and Gamma-ray Monitoring, by G. Corney

Film Measurement of Radiation Dose, by E. Jetter and H. Blatz

HIROSHIMA after A-bombing in 1945; almost before rubble settled, studies of bomb's effects were begun

Delayed Radiation Effects at Hiroshima and Nagasaki

By JOHN C. BUGHER
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On August 6, 1945, an atomic bomb was dropped over Hiroshima. Three days later a second such bomb was delivered over Nagasaki. With these two events, a completely new era in the application of force to decide human conflicts was born.

The loss of life was tremendous. Official estimates place the dead at 125,000, but unofficially the tally probably exceeded 200,000.

Injuries, both serious and minor, afflicted most of the surviving populations of the two cities. There was complete disorganization of community life. Panic and the disruption of all community services resulted in chaos. In contrast to the heavy bombing of cities such as Tokyo which ultimately produced nearly equivalent destruction, the cities of Hiroshima and Nagasaki ceased to exist as functioning entities.

The agreements made by the Japanese on their surrender were faithfully kept, and from the understandings early achieved there has come a cooperative study unique in character and of ultimate value to all mankind. This is the work of the Atomic Bomb Casualty Commission.

Within a few hours following the detonation of these bombs, Japanese scientists began observations which were subsequently of considerable value despite the incredible difficulties under which they were made. In the medical field especially they sustained interest and concern for the welfare of the people and a desire to obtain some measure of the extent of the disaster.

Of the first group of scientists reaching Hiroshima, the majority lost their lives in the typhoon which inundated the city a few days later. The survivors of this group were augmented by those who came later to form a nucleus of competent scientists who engaged in a survey of the effects of these bombs. When the American officers entered the area, it was possible to utilize the Japanese efforts and initiate a cooperative study which led to most of our direct knowledge of the effect of nuclear explosions on human beings.

To the Japanese as well as to the group of American military personnel who conducted these early studies (Dr. Shields Warren, Captain (MC), USNR; Brigadier General Elbert DeCoursey; Lt. Colonel George V. LeRoy; Lt. James V. Neel; and various others) it was apparent that there was a great need for a long-term study of the effects of these weapons upon the populations.

As a result of the initiative of this group, Secretary of the Navy James Forrestal recommended, and President Truman directed, on November 26, 1946, that a research organization for the study of the human results of the bombings be initiated by the

NEW LABORATORY and modern clinical buildings in Hiroshima comprise one of the major facilities of the ABCC

AS PART of genetics program, Japanese physician and nurse, ABCC employees, examine infant in Hiroshima home

The Atomic Bomb Casualty Commission is studying the latent effects on the surviving Japanese population. The good advances it is making toward its goal are revealed in this progress report

DOCTORS Hirosi Maki, Director, National Institute of Health, ABCC; Naoto Kameyama, President, Japan Science Council; and H. Grant Taylor, Director, ABCC

National Research Council, and supported by the Atomic Energy Commission. The Atomic Bomb Casualty Commission, has been directed in succession by Dr. Herman S. Wigodsky, Colonel Carl Tessmer, and currently by Dr. H. Grant Taylor.

In a Japan severely disorganized, with materials for construction and scientific study practically nonexistent, it was a tremendous task to formulate plans that were scientifically sound and materially practicable, and then to assemble the materials and construct the plant which would enable the necessary studies to be made. The early years were heavily burdened by the problems of developing the organization and its equipment. The fruits of these labors were to appear later.

Present Plant

The ABCC plan in its final form involved a central laboratory and administration at Hiroshima, with a smaller installation at Nagasaki. A third office in Tokyo has given valuable support to the main sections of the project in the two cities.

As the population returned and the cities were rebuilt, it was apparent that an adequate control population of persons not in the cities at the time of the bombings was being established. The entire study of each city could be conducted with good statistical controls drawn from the cities themselves without the necessity of duplicate construction in nearby communities.

The facilities at Hiroshima include modern clinical and research accommodations that are scientifically and medically entirely adequate for the task. These structures have been erected on the crest of a hill overlooking the city, and some idea of their extent and type can be gained from the photograph above that shows the Hijiyama laboratory and clinical buildings.

At Nagasaki a building belonging to the Department of Education was requisitioned and remodeled to serve the needs of this new organization.

Programs

The program assigned to ABCC is that of determining the long-range effects of the bombs on individuals themselves, i.e., the somatic effects, and the genetic changes as manifest in their children.

While the somatic effects are due to the changes produced in the tissues of the individual generally, the genetic effects are due to the impact of radiation energy on the chromosomes of the germ cells. The two series of events have thus very little in common, and the methods of one are in general not applicable to the studies on the other.

It was elected to make careful studies of the populations most heavily exposed to the bombs and through

various control means to maintain general surveillance of the people more remotely associated with the bombs and their effects.

To establish the groundwork for such operations, a complete radiation census of the two cities was undertaken. This task has been completed and forms the basis for the orientation of all of the scientific programs. The identity, age, sex, and residence of each individual is determined, and as precisely as possible, his location and position at the time of the detonations have been recorded. From this information not only will tabulations be made according to the distance from the hypocenter, but eventually measures of shielding and similar factors will be established.

The somatic studies bear upon all periods of the life span

A study of the effects of the detonations on children *in utero* at the time of the bombings has been completed. Some measure of the increased frequency of abortion and intra-uterine death has been made. The growth and development of the children who were exposed to the bomb's radiations are being measured, and as these individuals grow older they join the group of adults studied annually for any changes that may develop.

The genetic program is concerned chiefly with babies. Each expectant mother in the two cities is registered, and by so doing is entitled to receive extra rations in the second and third trimesters of pregnancy. Through the cooperation of the Society of Midwives, births are reported promptly and the ABCC staff doctors examine the infants for possible abnormalities (see photograph). Within a few weeks a second examination at the clinic is made to insure maximum accuracy.

The ABCC has a total staff of approximately 900 people, of whom 150 are American citizens. The medical and scientific staff is composed of both Americans and Japanese who work together in complete harmony. Most of the clinical departments are supervised by American doctors.

The system of patient finding, recording, and transportation is elaborate, smooth, and effective, and upon it the entire scientific structure necessarily is dependent. The observations are meticulously recorded and are subject to the most modern statistical analysis.

Work in Progress

Of the work in progress, only tentative statements may be made. Most of the activities will require several years for firm conclusions to be established. In certain fields, however, there are already indications which are more or less definitive.

Leukemia. It is now clear that among the persons exposed to the bomb within a radius of 2,000 meters there has been a marked increase in the frequency with which diseases of this general group occur. The precise magnitude of the increase is not yet clear since the cases are still developing, but it is obviously several-fold that of the normal incidence and is apparently of a magnitude similar to the experience among the roentgenologists of the United States. It appears that the increase in frequency of leukemia is related to the degree of exposure inasmuch as the frequency at greater distances diminishes. The suggestion has been made that the increase may be due to an acceleration in the rate of appearance of the disease so that individuals who in the course of ordinary events would have developed leukemia several years hence are developing it at an earlier age. This question cannot be answered for at least ten more years. There is no doubt, however, that the absolute increase in the incidence of leukemia is a real one.

Cataracts. In persons within 1,200 meters of the hypocenter, there has been an appreciable incidence of cataracts of all grades. Many of these cataracts are so small as to require special methods of examination for their detection. In the 1,200-meter survivors at Hiroshima, approximately one-tenth have shown lens changes of some degree. It is probable that most of these lenticular alterations were due to the neutron radiation since they appear to show a comparatively sharp boundary approximately 1,000 meters from the hypocenter in most directions. Whether the existing cataracts will progress or regress and whether additional ones will occur, only time can give the answer. It would appear that the peak of the development is now passed and the situation relatively static.

Dental manifestations. In children with developing tooth buds at the time of the detonations, there has been a significant increase in the frequency of enamel hypoplasia in the exposed as compared to the control groups of similar ages. There has likewise been some degree of delay in the eruption of teeth of these exposed children and a moderate increase in dental caries, particularly of the deciduous teeth of those exposed.

Growth and development. The general growth rates of exposed versus control children have not as yet shown any striking differences. The slight differences encountered may be due, it is thought, to other factors to which the population groups have been exposed in the intervening time.

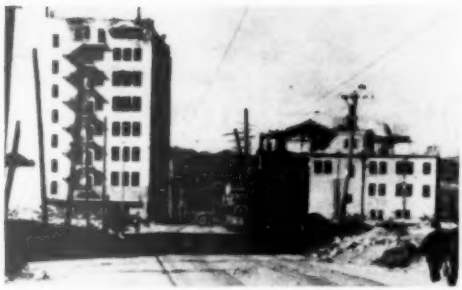
Hematology. The early studies by LeRoy and others clearly demonstrated the profound effects of bomb radiations on the white blood cells particularly. Subsequent studies by Snell, and more recent ones by Yamasawa, show that no permanent change has resulted and that no hematologic differentiation can be made between the exposed and the nonexposed populations.

Sociological and psychological. The ABCC program naturally involves all aspects of human change resulting from the bombs. With time, there will develop from the ABCC's experience and records an adequate portrayal of the sociological changes which have occurred in these communities. This, and the psychological field, are very difficult areas in which to conduct definitive studies and require careful and thoughtful analysis over a long period of time.

It is striking that the reactions of the two cities to essentially identical events were in themselves decidedly different. To an appreciable extent, the differences derive from the cultural dissimilarity of the two cities.

The people of Hiroshima are active, aggressive, and commercially conscious. With an amazing energy they have rebuilt the city in its entirety from the rubble of the old one. Its population is greater than ever. It is bursting with activity. There is a constant drive which shows itself in many ways such as the exploitation of the "Atom City" as a tourist center, and the building of a temple at the hypocenter.

At Nagasaki the restoration of the city is far from complete. In this old and traditionally closely-bound Christian community, the bomb produced more disruption than the purely



HIROSHIMA, 1945: Street scene following bombing

HIROSHIMA, 1949: Same street showing reconstruction

physical destruction. Families were separated and scattered; many survivors left the area not to return. Rebuilding has been steady and effective, but not with the flourish which has been so obvious at Hiroshima. The loss of the heavy industries and of the university have weighed heavily upon the people since these are facilities that can be replaced only slowly.

The appreciation of the psychological changes which the bombs may have wrought will likewise be a matter of time. It is superficial and easy to speak of psychological surveys, but actually such studies require careful attention by experts with a profound understanding of the culture and customs of the people. To those who would complain of the slow evolution of the psychological studies of the effects of these bombs upon the Japanese, I would point to the lack of effective studies on the psychological effects of these bombs upon our own people.

Genetic changes. Geneticists have consistently followed a program which will eventually give us a measure of the normal occurrence of mutations in man. They will also be able to give a precise answer to questions concerning the degree to which such mutations may be increased by exposure to radiation. From animal and plant experimentation conducted under the support of the Atomic Energy Commission at Brookhaven, Oak Ridge, and in various of the university laboratories, we know that mutation rates are increased as a result of exposure to gamma and neutron radiation. The increase in mutational frequency may vary widely, depending upon the form of life studied. It is materially impossible to infer the human rates from the animal experiments. This question must be answered by the studies now underway by ABCC in correlation with the radiation dosages delivered at various distances by these bombs.

ABCC studies involve both critical physical examination for specific defects which are now recognized as mutational in character and the subsequent statistical analysis of these results on the basis of the previous exposure of one or both parents. These results are compared with similar findings in children born of parents not present in the cities at the time of the attacks.

Up to date, over 50,000 babies have been so studied, and it is estimated that approximately twice this number will be required for the trend now apparent to be considered statistically significant. It has been found that detectable anomalies of a genetic character have appeared in 1.18% of the offspring of parents from the control population, while among the offspring of parents who showed evidences of radiation injury the corresponding figure is 1.40%.

Post-Treaty Relationships

In the years following the establishment of the program, the ABCC was technically a dependency of SCAP (Supreme Commander, Allied Powers) and received many services and courtesies from the organization of the Occupation. In its work with the Japanese people, it has functioned essentially as an independent organization and has achieved a commendable degree of scientific cooperation. With the end of the Occupation, and the return of her sovereignty to Japan under the Treaty, ABCC must continue as a genuinely cooperative venture of Japanese and American scientists. On July 1, 1951, the management of the organization was assumed by the National Academy of Sciences, the incorporated parent of the National Research Council. Its counterpart in Japan is the Japan Science Council.

Further, there has been active interest and cooperation on the part of the various branches of Japanese medicine, especially the Japanese Society of Pathology.

As an indication of its fundamental interest in the ultimate value of this program, the Japanese Government has made extensive concessions and contributions to the stability and effectiveness of the organization, and likewise, the Government of the United States, through its diplomatic and military representatives, has made appreciable contributions to the ease of operation and the recruitment of personnel. The financial support will continue to be maintained by the Atomic Energy Commission, with members of the staff of the Division of Biology and Medicine participating with representatives of various universities in a committee which is advisory to the National Academy of Sciences, the operating organization.

As the studies progress to a definitive state, they are being published in the scientific literature of the United States and Japan on a wholly unclassified basis. Some of the results mentioned here are as yet only tentative and are not to be regarded as final in character.

* * *

This article is based on a paper presented before the Radiation Division, American Industrial Hygiene Association, Cincinnati, Ohio, April 24, 1952.

Autoradiographic Method for Identifying Beta-Active Particles in a Heterogeneous Mixture

Radioactive particulate matter produced by abrasion or grinding can be observed and measured directly using a new method for checking air samples. It is especially applicable to ventilation and exhaust-control studies

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With the autoradiographic-optical technique developed at this laboratory, it is possible to collect a mixed radioactive and inert aerosol sample on a thin transparent surface (glass, plastic, or molecular filter material, for example), autoradiograph it, and determine microscopically the statistics of its beta-gamma-emitting members.

Assuming the total volume of air sampled and the gross activity of the collection slide to be known, the size distribution of the active particles can be measured to find area and volume distributions, the active and inactive particles per unit slide area can be counted to determine the active fraction of the gross collection, and the number of active particles and their activity per unit volume of air can be obtained. The particles are never disturbed from their sites of deposition on the collection slide.

In its simplest form, autoradiography involves placing a film in contact with the object and, after a suitable exposure period, removing and processing it. The resultant image mirrors in a qualitative way the various activity levels of the object.

Since it is extremely difficult to realign the film precisely with the object, the location and examination of the origin of the ionizing radiation in the sample is generally impossible. With thin transparent specimens, such as histological sections, it is possible to leave specimen and film in contact throughout exposure, processing, and microscope examination, thereby greatly facilitating precise location of radioactive sites. This method may be used only with specimens that allow diffusion of the processing solutions to the plate. With nonpermeable samples, stripping film may be used. Such film allows access of the developer directly to the emulsion, the sample being in contact with the reverse or acetate face of the film. The acetate support of stripping film provides a physical separation of source and emulsion.

Normally, intimate contact is desirable for maximum resolution, but, in the application described here, the separation of specimen and emulsion is a requisite part of the technique.

Approach to the Problem

The problem was to detect and size the radioactive component of a mixed radioactive and inert aerosol. The particles composing this aerosol were heterogeneous with respect to size, shape, and composition. Further, the radioactive members contained various beta-gamma emitters whose maximum energies covered a wide spectrum.

A *Gel placed on dust surface of slide which is cemented to cover glass*

B *Stripped film placed on sample, with emulsion side up*

C *Appearance after exposure and photographic processing*

D *Inverted on mount for examination with vertical illuminator*

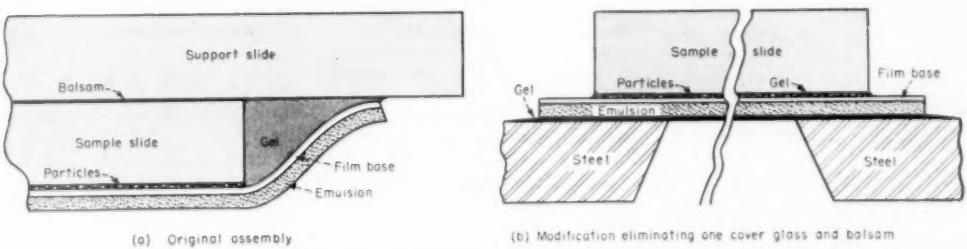
FIG. 1. Procedure for preparing and examining autoradiographic slides

Autoradiography was considered the most promising method to use. To make results positive and unequivocal, it was decided that once the particles and the photographic plate were placed in contact, they must not be separated or disturbed throughout the stages of exposure, development, and microscopic examination.

Two general methods of autoradiography are in common use: track autoradiography, in which tracks are produced by individual beta particles and recorded by the emulsion (*1*); and contrast autoradiography, in which, instead of individual tracks, a dense black area about the radioactive source is formed from the silver halide grains in the vicinity rendered developable by the passage of many beta particles.

Track method. This is the more sensitive detector of beta activity, but the difficulties peculiar to autoradiographing a deposited aerosol render it unfeasible for these reasons:

Consider a range of particle diameters of 0.01 micron to 10 microns (a common occurrence) in the deposited aerosol. If the activity of a particle is proportional to its diameter, the largest would have an activity of 10^3 times that of the smallest. For activities proportional to surface and volume, the factors would be 10^6 and 10^9, respectively. It is impossible to



(a) Original assembly

(b) Modification eliminating one cover glass and balsam

FIG. 2. Autoradiographic assemblies in cross section, with relative thicknesses drawn to scale

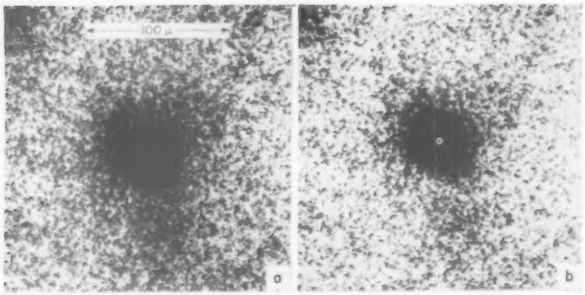


FIG. 3. Photomicrographs of same autoradiograph made with (a) substage illumination and (b) substage and vertical illumination

expose emulsions to activity ranges of these magnitudes and obtain a distinguishable or countable number of tracks about both the large and small particles. Since a nuclear track is composed of a faint wandering path of silver grains, each grain of which has a diameter around 0.3 micron, the smallest aerosol particle that could be differentiated from a silver grain would have to be greater than 0.3 micron. Therefore, certain identification of many aerosol particles up to perhaps 0.5 micron would be doubtful.

The emulsions best suited for beta-track autoradiography are unfortunately also the most sensitive to background fogging. Also, emulsions, in general, are not capable of recording tracks from individual beta particles. The few emulsions that can, are limited to low-energy particles.

Thus, hope of determining the specific activity of any detected active particle by track counting was abandoned in favor of the contrast method.

Contrast method. Not only does this method minimize the difficulties associated with track counting, but it widens the choice of suitable emulsion and film types. The chances of successful detection of active particles increases, since it is inherently easier and faster to pick out a clump of silver grains of higher concentration than background than it is to distinguish a trail of widely spaced grains through a background pattern of fog grains.

Experimental Techniques

In the first application of the technique, the aerosol was electrostatically deposited on small slips of thin microscope cover glass, about 5 by 7 mm. The practical problem was to bring the deposited aerosol into contact with a film in such a manner that it could be exposed, developed, and subsequently viewed without separation.

Numerous attempts were made with nuclear plates, but, with the aerosol already deposited on glass slips, all attempts to mount them face down on the emulsion failed because no mounting medium could be found that would allow normal development and fixation to be carried out in the emulsion under the glass sample slip. It became apparent that any autoradiographic method that places the particles on or in the surface of the photographic emulsion is doomed to failure because small particles become inextricably confused with surface fog grains in the emulsion. To provide a separating barrier between the plane of the particles and the surface of the emulsion, a stripping film was used.

Briefly, stripping film consists of an emulsion on a thin cellulose ester support that may be stripped from its heavy cellulose backing and placed over the object to be radiographed (*2*). The important feature of stripping film is that the object may be exposed to the emulsion through the thin support, leaving the face of the emulsion accessible for processing.

Small squares of stripped film were cut preparatory to placing them on the slides which, in the meantime, had been cemented with balsam, particle side out, to large cover glasses to facilitate handling. A drop of warm glycerin gel was placed on the slide surface and allowed to run out into a thin film. Then a piece of the stripped film was placed over the slide, support side in contact. Figure 1 illustrates the steps in the preparation of an autoradiographic assembly.

The specifications on the adhesive used between the film support and the glass are exceedingly rigid and caused some trouble. (A satisfactory mixture was eventually found, and a number of exposures made. Details of this problem and the composition of a suitable gel are given later.)

Upon setting, the gelatin bond between film and glass shrinks and pulls the film into smooth contact with the particles and does not loosen or come off in the photographic processing.

Figure 2a is a schematic diagram of the completed assembly with thicknesses drawn approximately to scale. Figure 2b shows a modification in which a stainless-steel plate with a hole drilled in the center was used in place of the large cover glass. The purpose was to eliminate the balsam layer and to reduce the thickness of glass through which the objective must work to reach the plane of the particles. In either type of mount, the beta particles penetrate the film support and register in the emulsion.

Eastman Kodak Stripping Film was used in the only emulsion type, NTB, in which it was available at the time.* For NTB stripping film, the manufacturer reports sensitivity to electrons up to 50 kev, which means, in effect, a rather low geometry for beta emitters of a few Mev maximum energy.

Exposure times were determined empirically. A few successful exposures made it possible to relate activity of a slide by Geiger-Müller counter to exposure time. Development in D-19 was standardized at 68° F for five minutes, followed by normal rinsing, fixing, and washing. It remained to devise a method of viewing the radioactive particles themselves.

The dilemma of a dense spot in the film, designating the presence of an active particle while at the same time obscuring it, was resolved by the use of overstage or vertical illumina-

* A new product, Eastman J-3 18301 Autoradiographic Permeable Base Stripping Film Experimental, became available in December, 1951. Emulsion sensitivity is reported to be between NTA and NTB. The permeable gelatin base, only 5 microns thick, is a feature which should provide versatility of utilization not previously possible. Type NTB-3 emulsion, sensitive to electrons up to 0.4 Mev would be more satisfactory, but to date Eastman has not made available a stripping film coated with this emulsion (*3*).

tion, similar to that used in metallographic microscopes for opaque objects. There are a number of illuminators commercially available which, when attached to an ordinary microscope body tube, serve to focus light onto the specimen from above. Placing the autoradiograph assembly under the microscope with the particle plane above the plane of the emulsion enables the overstage light to reach the particles on top of the autoradiographs, making them visible.

Figure 3 is a pair of unretouched photomicrographs of the same autograph, illustrating the appearance of the radioactive particle when vertical illumination is used in conjunction with substage illumination. The halo about the particle is an optical effect possibly due to reflected light from the distorted gelatin-acetate interface under the particle.

Two types of illuminators were used: the Bausch and Lomb Vertical Illuminator, which utilizes a standard objective as both objective and condenser for a built-in light source, and the Leitz Ultrapak, which comprises a special objective and surrounding condenser so designed that light from an incorporated source passes down around the objective to the specimen. The Leitz instrument appears to be superior in reducing glare and minimizing interference fringes from accidental air spaces in the autoradiograph assembly.

Oil immersion objectives could not be used because of their short working distances. It was hoped that the modified assembly using a stainless-steel plate would minimize the distance between cover glass surface and particle plane sufficiently to allow their use. The particles could indeed be observed, but the autoradiographs under them were out of reach. Since it was inconvenient to find an autoradiograph with a dry objective and then locate the particle with an oil objective, it was not attempted.

As mentioned previously, the vertical separation between autoradiograph and particle (10-micron film support plus gelatin film) was an indispensable aid in locating the object, especially in the case of a sparse autoradiograph and a small particle. The focal plane of the objective had to be raised above the plane of the autoradiograph to focus on the particle which, at the relatively high magnifications used (600–900×), threw the distracting silver-grain background out of focus.

Discussion

The requirements on a bonding medium between the film support and glass slide are stringent. The adhesive must: (1) set up volume-wise to avoid dry edges and a tacky center, (2) be transparent and structureless under the optical microscope, (3) be insoluble and inert in photographic solutions, (4) not dissolve the cellulose ester film support and reach the emulsion, and (5) shrink on setting to produce a smooth, tight bond between film support and slide. It should be easy to handle for assembly under a dark red safelight.

It was originally planned to use gelatin as this adhesive, and a 1% solution in water was tried. It was apparently successful, meeting all the above requirements. However, several weeks after processing, some deterioration was noted.

A search for a better adhesive included such materials as starch solutions, water glass, Formvar, lacquer, Lucite in acetone, and others, but nothing was found which even approached gelatin in suitability.

It was then decided to alter the simple gelatin-water solution to increase its stability. A number of formulas (*4*) were considered, most of them variations of much the same composition. After some experimentation, the recipe below was selected:

Gelatin Bonding Medium

(1) Dissolve 100 mg chrome alum in 15 ml water with heat.
(2) Add 1 gm gelatin to 35 ml hot water.
(3) Add 2 ml glycerin to gelatin with constant stirring (warm).

This mixture is very satisfactory, and the hardened gelatin film in the completed autoradiographic assembly has proved to be stable.

The stock gel, which was kept in the liquid state for convenient use, displayed no such stability, developing many colonies of mold and/or fungus growths within a few weeks. Fungicides were ineffective. Since fresh, untreated gel is apparently immune to fungi after hardening in a thin film, the contamination problem may be avoided by mixing fresh gel when desired.

The optical methods used in the measurement of the particles detected with this system are subject to the same difficulties and shortcomings associated with the use of any optical-microscope system for measuring particles. That is, apparent sizes approaching the limit of resolution of the system may vary considerably from actual. Particles below the limit of resolution may be imaged as diffraction disks larger than their true size (*5*) or, if small enough, go undetected; and particles whose indexes of refraction approach that of the medium (gelatin) may be invisible even though the size is well above the limit of resolution (*6*).

These experiments yielded very little quantitative information on the resolving power or ability to distinguish active particles close to another active or inactive particle. Concentrations of active particles, 95% of which were less than 5 microns in diameter, ranged up to 300 particles per square millimeter and were easily resolved. It is evident that resolution depends on aerosol particle size, specific activity, type of beta emitter, emulsion type, exposure time, development, and geometrical factors.

Only qualitative information on the specific activity, i.e., activity per unit volume, of individual particles could be obtained using the size and density of the autoradiographic image as an index. Initial steps have been taken on the development of a method of producing radioactive spherical particles of known specific activity to serve as calibration standards. With these standards, a more detailed study of the autoradiography of particulate matter will be undertaken.

* * *

This article is based on a paper presented before the Radiation Division, American Industrial Hygiene Association, Cincinnati, Ohio, April 24, 1952.

BIBLIOGRAPHY

1. D. Campbell. Track autoradiography with Fe^{59} and S^{35} with quantitative evaluation, *Nature* **167**, 274 (1951).
2. G. A. Boyd, A. I. Williams' Stripping film techniques for histological autoradiographs, AECD-2066 (1948).
3. W. F. G. Swann, Bartol Research Foundation, private communication (1950).
4. C. P. Shillaber, "Photomicrography," p. 498 (John Wiley & Sons, Inc., New York, 1944).
5. E. M. Chamot, C. W. Mason, "Handbook of Chemical Microscopy," 2d ed., p. I-40 (John Wiley & Sons, Inc., New York, 1938).
6. W. D. Foster, H. H. Schrenk. Petrographic identification of atmospheric dust, Bureau of Mines R. I. 3368 (1938).

Status of Neutron Dosimetry

Present devices for measuring tissue dose delivered by neutrons of any energy are equally sensitive to gamma radiation. Instruments that are insensitive to electromagnetic radiation can be used only in a limited range of neutron energies. Problems in dosimetry of fast and slow neutrons are discussed

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THERE IS NOW general agreement that the best physical index of the biological effect of ionizing radiation is the energy absorbed by the tissues exposed. The unit of dose may be the erg per gram of tissue—as recommended by the 1950 International Congress of Radiology—or the rep (roentgen equivalent physical—suggested by H. M. Parker) which has been used for a number of years and is now defined as the dose of any ionizing radiation that results in the absorption of 93 ergs per gram of tissue.

With such a unit generally accepted, the practical value of any measurement of neutron dose depends on how accurately its result can be expressed in terms of energy absorbed in tissue. The precision with which an intermediate measurement is made is of secondary importance. Thus, neutron flux may sometimes be determined rather accurately, but, since equal neutron flux may give rise to varying tissue dose depending on neutron energy, the flux figure is of limited usefulness unless information on the energy distribution of neutrons and of corresponding cross sections is also furnished. This is usually not available in any detail, and dosimetry based on flux is likely to be unsatisfactory.

Tissue-Equivalent Chambers

At present, the most direct method of determining energy absorbed per unit mass of tissue is based on the Bragg-Gray principle. This theorem relates ionization in a gas-filled cavity to energy imparted to a solid surrounding the cavity. If the cavity has the same atomic constitution as the solid, its size and shape become irrelevant and the relation becomes particularly simple in that the energy imparted per unit mass of gas is directly proportional to the ionization. The factor of proportionality is usually designated by W and represents the average energy expended by ionizing particles in the production of an ion pair. Its value varies little with the nature or the energy of the ionizing particle.

Since the material in which one wishes to determine energy absorbed is tissue, both the wall and the gas of the chamber must be tissue-equivalent (*1*). This may be done by choosing a gel of proper proportions for the former and various mixtures of gaseous components for the latter. An excellent solid substitute for the gel—at least for neutrons from 0.5 to 14 Mev—is a conducting plastic having the same hydrogen and nitrogen content as the gel. At our laboratory, chambers of this type have been built which embody no metals. This type may also be used for slow neutrons since it contains no significant amount of materials which can be rendered radioactive by neutron capture.

However, besides registering the tissue dose due to neutrons, these chambers will also simultaneously determine the tissue dose due to any other ionizing radiation such as, for instance, gamma radiation. The biological effectiveness of these radiations is not the same, and at present the permissible exposure to gamma radiation represents a dose which is ten times higher than the corresponding value for fast neutrons. Thus in a "mixed" radiation field an evaluation of the health hazard requires a knowledge of the separate doses contributed by gamma radiation and heavily ionizing particles. It is believed, at present, that the difference in biological effectiveness is due to a difference in the specific ionization of the ionizing particles produced in the two instances.

Fast-Neutron Dosimeter

A dosimeter designed by Hurst and Ritchie (*2*) takes advantage of the difference in specific ionization. It consists of a proportional counter in which pulses due to electrons are discriminated against. Recoils (primarily protons) which are produced by neutrons are counted. The yield of these particles at different neutron energies is adjusted by choice of the gas filling and by proper design of the front wall of the counter so as to give a counting rate which is proportional to the dose delivered through a considerable range of neutron energies.

The instrument suffers from the drawback that it is directional in the sense that only neutron radiation

incident from one direction will be measured properly. Furthermore, its calibration depends on a number of data which are difficult to assess with great precision. Nevertheless, it is the only device available at present which presumably will selectively determine a fast-neutron dose, and it would appear likely that at least in some protection measurements its accuracy is sufficient. This instrument is now commercially manufactured by Radioactive Products, Inc., Detroit, Michigan.

Both the Oak Ridge group and our laboratory at Columbia University have done some work on a nondirectional proportional counter in which the ionization due to heavily ionizing particles is amplified linearly in the counter itself and then further amplified electronically and added to give the total dose. The technical complexities of such a device are considerable, and it does not seem likely that it will be very useful in routine survey measurements.

Subtractive Measurement

Another possibility for determining the neutron dose in a "mixed" radiation field is to obtain it by subtraction. This may be done by measuring the total tissue dose with a tissue-equivalent ionization chamber and by determining the gamma dose with a dosimeter which is insensitive to neutrons. However, an accurate determination of the gamma dose in such a field is also quite difficult. The wall materials of so-called air-equivalent ionization chambers will always exhibit a definite response to fast neutrons. Even a carbon chamber containing carbon dioxide, which is perhaps the best combination for such a device, may register about 10–20% of the reading obtained with a tissue-equivalent chamber when exposed to a reasonably "pure" neutron field in the neighborhood of 14 Mev. At lower energies the error is less, but it probably does not become negligible until the neutron energy is of the order of 1 or 2 Mev.

Geiger counters, especially when devoid of hydrogenous wall materials, are sufficiently insensitive to neutrons, but it is difficult to construct a counting-rate meter which does not show a dependence on gamma-ray energy. Once such an instrument is available it will be not only an excellent dosimeter for gamma rays but also indirectly a tool for determining neutron dose.

Thermal-Neutron Problems

Matters are still more complex in the measurement of thermal neutrons. The two main reactions which impart energy to tissues exposed to slow neutrons are the $N^{14}(n,p)C^{14}$ reaction which gives rise to a short-range proton, and the $H(n,\gamma)D$ reaction which gives rise to a very penetrating gamma ray. As a result both the total dose and the fractions of the dose which are contributed by particles of widely different specific ionization (protons and electrons) depend strongly on the geometry of both the neutron beam and the biological object irradiated. Thus in a wide beam of neutrons, an increasing mass of tissue will quickly reach equilibrium dimensions for the nitrogen reaction since this merely requires that its diameter be large compared with the proton range which is a fraction of a millimeter. However, because of the great penetration of the gamma rays produced, an increase of the mass irradiated results in a more copious production of gamma radiation which raises the dose at each point throughout the structure. Equilibrium would be approached only if the dimensions of the biological object became much greater than the half-value thickness of tissue—a situation which will never be attained in practice.

It can be seen that for similar reasons the relative dose due to gammas as compared with the proton dose will increase as the size of the neutron beam which traverses a large biological object is increased. Here again irradiation of additional volume creates a larger distributed source of gammas.

A further complication in the measurement of thermal neutrons lies in the fact that many materials—such as most commonly used metals—may be rendered radioactive by slow-neutron bombardment. This would necessitate difficult corrections of experimental results.

As noted, these difficulties have been avoided in tissue-equivalent ionization chambers, which can be used to measure the total tissue dose. Because of low total neutron cross sections, chambers lined with either carbon or beryllium and filled with such gases as CO_2 or O_2 may be expected to be quite satisfactory as selective gamma dose meters. Since the proton is dissipated in the immediate vicinity of its origin and since the energy distribution of a neutron beam, once it is thermalized, remains unchanged, the dose due to protons should at each point be proportional to neutron density. The latter may be measured by means of activation of foils. Studies of this nature can be expected to yield data on the total tissue dose and on both its densely and sparsely ionizing components. The results of such a comparison should be of value in testing the validity of concepts described here.

* * *

This article is based on a paper presented before the Radiation Division, American Industrial Hygiene Association, Cincinnati, Ohio, April 24, 1952.

BIBLIOGRAPHY

1. H. Rossi, G. Failla in "Medical Physics," O. Glasser, ed., vol. 2, p. 603 (The Year Book Publishers, Inc., Chicago, Ill., 1950)
2. G. S. Hurst, R. H. Ritchie, N. H. Wilson, *Rev. Sci. Instr.* **22,** 981 (1951)

Five Ways to Use Strippable Coatings

Strippable coatings—formulations of vinyl plastics—have excellent resistance to corrosion and are quite durable. They have proved satisfactory for many radioactivity applications, including:

1. **Protective covering.** Surfaces exposed to a high probability of contamination—inside a fume hood, walls behind work surfaces—can be covered.

2. **Sandwich coat.** Contamination can be pinned down for removal by spraying a strippable coat over it.

3. **Packaging material.** Any size equipment can be covered. Web-type coatings will span gap of 30 in. or more. Second coat forms smooth, neat package.

4. **Secondary container.** Glass or fragile vessels can be coated. If container breaks, coating will prevent contamination from spreading.

5. **Sealing material.** Moisture and vapor-proof seals for corks, lids, and covers are easily formed.

—*O. M. Bizzell, in paper at Radiation Division, American Industrial Hygiene Association, Cincinnati, Ohio, April 24, 1952*

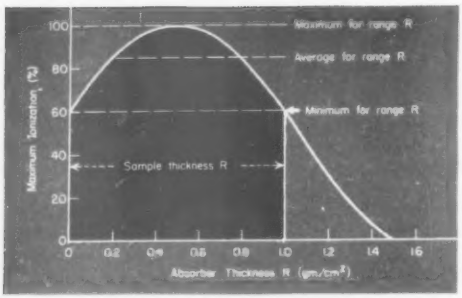

FIG. 1. Complete sterilization of the sample with a single cathode-ray beam requires an ionization level within the sample thickness (*R*) above the minimum level, 60% of maximum ionization, at the upper and lower surfaces

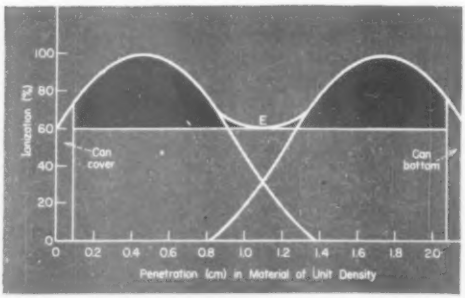

FIG. 2. Cross firing two 3.1-Mev beams gives more efficient ionization of material in a steel sardine can. The cover and bottom of can absorb 17.5% of the total dose. Overdose, dark areas, is 26.7%. Minimum ionization level is at *E*

Evaluation of

Food Sterilization Efficiency

If absorber and equipment characteristics are known, optimum conditions can be determined for irradiation of foods with high-energy cathode rays

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INVESTIGATIONS conducted during the past six years at Massachusetts Institute of Technology and elsewhere have indicated that sterilization of foods and drugs by ionizing radiations is possible (*1–5*). More efficient utilization of cathode rays has been achieved.

Cathode-ray penetration of matter, approximately 1 cm for each two million volts, causes maximum ionization at about one third of the maximum range of the electrons. The total dose required for sterilization of a sample of given thickness is determined by the point of minimum relative ionization. For the most efficient use of a single beam, these points should be at the upper and lower target surfaces, as shown in Fig. 1 (*6*).

When a sample of thickness *R* is treated by a single beam of cathode rays, *i. e.*, when the rays are fired in one direction only, the energy expended beyond *R* (unshaded portion under curve in Fig. 1) is wasted. In the case of the sample of $\frac{3}{5}$ R_{max} thickness in Fig. 1, this wasted energy is approximately 15% of the total dose, the latter being represented by the total area under the curve.

Cross-Firing Beams

For more efficient use of the cathode-ray beam, solid samples may be treated by "cross-firing"—*i. e.*, by exposure to beams coming from opposite directions through two ports. This can be accomplished with conventional radiation equipment either by breaking down a single beam and bending part of it electromagnetically or by using two opposing accelerators.

The increase in ionization to a maximum at $\frac{1}{3}$ R_{max} is inherent in the effect of cathode rays on matter. Figure 2 illustrates the most efficient energy distribution that can be obtained with cathode rays. Hence the ionization at the center, *E*, is the same as at the outside surfaces and is the determining point of sterility. Figure 3 shows the advantage of using an aluminum container.

If the accelerating voltage used is too low or too high, relative to the thickness of the absorber, the utilization of the radiation is inefficient, as shown in Figs. 4 and 5.

The lateral variation in dose may be as much as 50% when a raw cathode-ray beam is used (Fig. 6). However, by means of a new technique for scanning the beam uniformly over a given area, as shown in Fig. 7, this variation can be reduced considerably. The beam is electromagnetically swept back and forth over the sample at a rate of 200 cycles per second, which results in a uniform distribution of the beam. Because the angle of scanning is 16 degrees, the width of the beam traverse is determined by the vertical

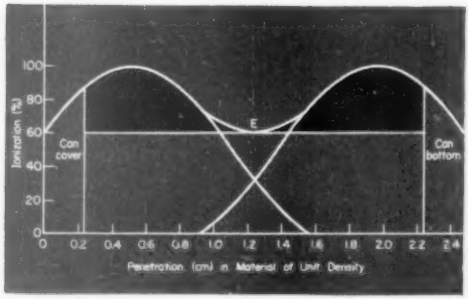

FIG. 3. With an aluminum sardine can, the same relative ionization can be accomplished by 2.75-Mev cathode rays—penetration of cathode rays in matter is an inverse function of density. Only 6.2% of the total dose is lost in the can covers

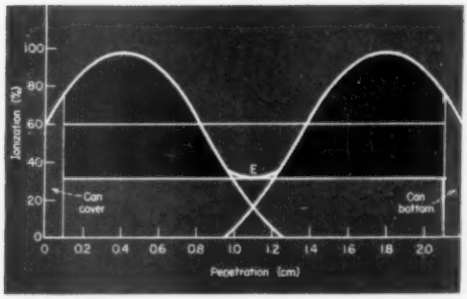

FIG. 4. If the accelerating voltage is too low, the radiation is used less efficiently. With 2.5-Mev cathode rays, the overdose (dark areas) is 59.4% of the total dose. Again, the dose insuring sterility is based on point *E* at the center

distance between the sample and the scanning coils. This distance can be made great enough for the beam to traverse a sample of almost any width.

To insure complete coverage, there should be an overscan of approximately one full spot size on each side of the sample. With a spot of $\frac{3}{8}$-in. diameter and a sample 4 in. wide, the loss in energy as a result of overscanning is

$$\frac{2 \times \frac{3}{8}}{4} \times 100 = 18.8\%$$

As the width of the sample is increased, however, the efficiency of utilization of the beam is increased, becoming 7.5% for a 10-in. sample.

Power Requirements

The power of a given cathode-ray accelerator is given by

$$P = I \times E \times \text{Efficiency Factor}$$

where P represents the power; I, the accelerating voltage; and E, the total beam current.

Under optimum conditions, an efficiency of beam utilization in depth of up to 75% (including both product and container) can be expected. With a 10-in. beam, the lateral efficiency is 90% or better. Under these conditions, therefore, the efficiency factor would be $1.00 - 0.25 - 0.10 = 0.65$.

With a 3-Mev beam of 4-ma total beam current and an efficiency factor of 0.65, the power available to the sample is 7,800 watts, or 7,800 joules per second.

If a sample of material requires a dose of 2×10^6 rep to sterilize it, the power requirement is 16.6 joules per gram, assuming that 1 rep equals 83 ergs per gram. With a total beam input of 7,800 joules per second, the total amount of material that can be handled is 469 gm/sec, or 3,722 lb/hr. The quantity of material that can be handled is reduced accordingly if an accelerating voltage below or above optimum is used.

By obtaining simple data as to the size of the absorber (material to be irradiated), its density, and the specifications of the irradiation equipment, the throughput of a particle accelerator into a given product can be readily calculated and the optimum specifications for the cathode-ray equipment can be determined.

BIBLIOGRAPHY

1. C. G. Dunn, W. L. Campbell, H. Fram, A. Hitchins, *J. Applied Phys.* **19**, 605 (1948)
2. J. G. Trump, R. J. Van de Graaff, *J. Applied Phys.* **19**, 599 (1948)
3. B. E. Proctor, S. A. Goldblith, H. Fram, *Food Research* **15**, 490 (1950)
4. B. E. Proctor, S. A. Goldblith, *Food Technol.* **5**, 376 (1951)
5. B. E. Proctor, S. A. Goldblith, *Advances in Food Research* **3**, 119 (1951)
6. J. G. Trump, K. A. Wright, A. M. Clarke, *J. Applied Phys.* **21**, 348 (1950)

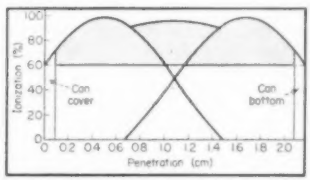

FIG. 5. With too great an accelerating voltage, a large overdose results. Shaded areas show overdose of 35.8% with 3.0-Mev cathode rays. Minimum ionization is at can surfaces

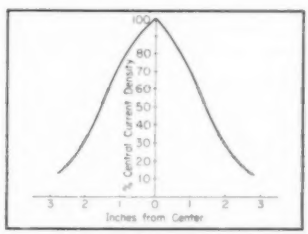

FIG. 6. With a raw cathode-ray beam, there is a lateral variation of beam density

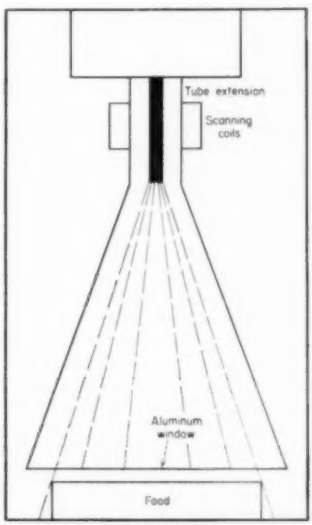

FIG. 7. Lateral variation is reduced considerably by scanning beam over target

An inexpensive system for automatically counting and recording the activity of many samples over long periods of time has been developed. Design and operation of the system is described in detail

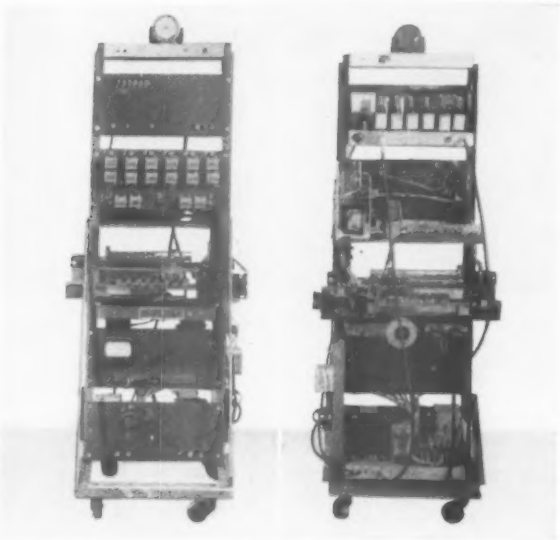

FIG. 1. Front and rear views of the automatic counter

A Simple Automatic Counter

By G. A. SHIRN and E. S. WAJDA
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THE NEED FOR counting many radioactive samples for fairly long periods of time often arises. For instance, one of the most direct ways of studying diffusion phenomena in metals is by the use of radioisotopes as tracers. In this method, a tracer placed on one end of a metal specimen is allowed to diffuse into the bulk of the specimen under controlled temperature and time conditions. Thin uniform sections of sample are then cut and the activity of each section measured.

In our studies of anisotropic self-diffusion in zinc, we usually employed ten or twelve sections. Since the activity of each section was comparatively low, a long counting time was necessary for good statistical accuracy. Therefore, a counting system was developed in which all samples are automatically counted and their activities recorded in a 16-hour run. The counter is shown in Fig. 1.

The automatic counter consists of a G-M tube mounted in a traveling carriage which is positioned successively over each sample and over a background position. The output from the tube is fed into a conventional scaler unit which actuates individual registers for each sample and background position. The need for a background count after each sample count arose from serious background variations over the total counting time for an entire set of samples.

Timing Control, Recording

The heart of the entire mechanism is the timing control shown in Fig. 2. A diagram of the automatic counter is shown in Fig. 3.

The timing control consists of a Bodine (type KYC-23) synchronous motor, M_t, geared down to one revolution per hour. A cam, A, on the final gear actuates a microswitch, B, once every revolution. This in turn energizes the coil, C, of a rotary sequence switch, D, which starts one of the position motors, M_r or M_l, moving the carriage, E, to the next position.

A series of limit switches, S_r, at the sample, or at the background position, S_b, stops the counter carriage and driving motor. These limit switches are interconnected with the sequence switch to provide for the proper carriage position. Other counting periods may easily be obtained simply by changing gears in the timing gear train.

The output from the G-M tube is fed into a standard scale-of-64 Higinbotham-type scaler, and then to the proper register by the register switch, S_r. This slider-type switch, shown in Fig. 4, is actuated by the counter carriage in one direction only. Since the register switch is interconnected with a single-pole, double-throw switch, S_c, at the background position, the proper background register is con-

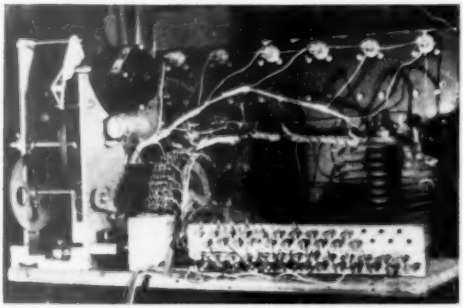

FIG. 2. Timing mechanism showing gear train, timing cam, and sequence switch

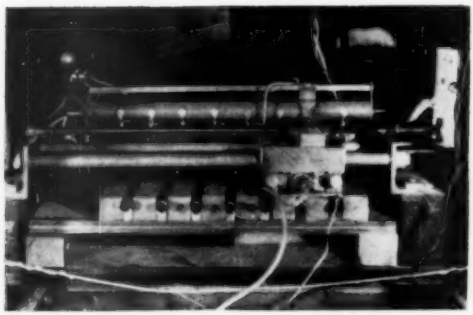

FIG. 4. Arrangement of register switch, counter-tube carriage, and samples

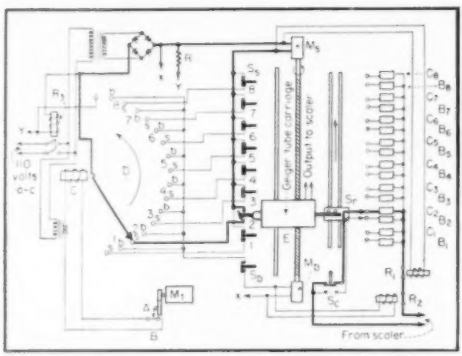

FIG. 3. Schematic diagram of the automatic counter

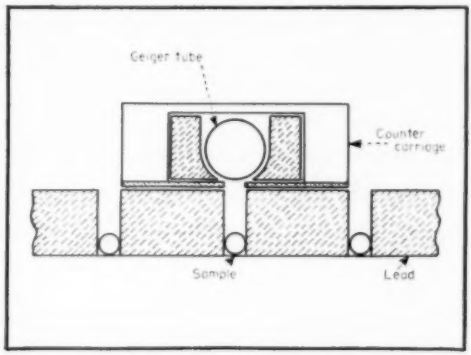

FIG. 5. Lead shielding around G-M tube and samples

nected when the carriage reaches the background counting position.

While the counter carriage is in motion, a set of relays, R_1 and R_2, disconnect the counter from the registers to avoid spurious counts.

Typical Operation

To demonstrate a complete cycle of operation, begin with the counter carriage in sample position 2, as shown by the heavy lines in Fig. 3. When the counting period is completed, the sequence switch, D, closes contact 2*b* and opens contact 2*s*. This energizes the motor, M_b, which drives the counter carriage to the background position, and also operates relay R_2, disconnecting the counter from the registers.

When the carriage reaches the background position, it disconnects motor M_b through switch S_b, and also switches the scaler to the proper background register through switch S_c.

At the end of the background count, the sequence switch, D, opens 2*b* and closes 3*s*. This energizes motor M_s through the limit switch 3, driving the counter carriage to sample position 3. While the carriage is moving to position 3, it moves the register switch, S_r, from position 2 to position 3, thus connecting the scaler to the register, C_3, through the single-pole, double-throw switch, S_c.

The cycle is repeated until all the samples are counted. The next position of the sequence switch, D, shuts off the entire automatic counter.

Shielding

The samples to be counted are radioactive metal chips dissolved in HCL and scaled in small glass tubes. In our experiment, we used a Zn^{65} tracer which emits 1.1-Mev gamma rays. Special shielding precautions have to be taken so that no radiation effects from neighboring samples are encountered.

Lead blocks were used to separate the radioactive samples (Fig. 4). To improve the shielding still further, two lead blocks were placed inside the counter-tube carriage, and a lead plate with a slot cut in the middle was fastened to the underside of the counter carriage (Fig. 5). This arrangement provides for the same solid angle subtended by each sample at the Geiger counter.

When more shielding is required for more energetic samples, alternate counting positions can be used or the sample shelf can be extended to give greater separation between samples.

The automatic counter can be easily adapted to any problem which involves the counting of many samples for long periods of time. In the present design, there is provision for counting eight samples, but this may easily be extended to any number of samples.

* * *

This equipment was developed as part of a program sponsored under AEC contract No. AT-(30-1)-1044, under the direction of Dr. H. B. Huntington.

Pulse-Amplitude Analysis in Nuclear Research

PART III

MULTICHANNEL ANALYZERS

This article considers analyzers in which pulse-height selection is accomplished by mechanical means, thermionic diodes, trigger circuits, a sorting-ladder circuit, and by beam-deflection techniques

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A MULTICHANNEL pulse-amplitude analyzer is a device which sorts voltage pulses into a number of "channels," or "windows," in accordance with their amplitudes. Such a device, called a pulse sorter, kicksorter, pulse spectrograph, or quantizer, can take many possible forms.

A multichannel analyzer is most easily constructed by cascading a number of level selectors to define intervening channels. As in a single-channel analyzer, an input pulse causes an output count to be registered by the anticoincidence circuit of a channel when only its lower-level and not its upper-level discriminator is actuated.

In general, therefore, the design problems peculiar to a single-channel analyzer are also met in a multichannel system. For example, level-crossing information must be stored if reliable anticoincidence operation is to be obtained. If a reasonable degree of energy-level resolution is required, many channels are required, and the analysis equipment becomes bulky, costly, and susceptible to failure.

The effective application of a multichannel analyzer requires careful thought. One might assume, for example, that the greater the number of channels, the greater the available resolution in the definition of a distribution curve. However, the resolution of an associated detector system should not be neglected.

Kelly (*30*) has described some considerations governing the choice of channel width and number of channels for an amplitude analyzer operated in conjunction with a scintillation detector. The statistical behavior of a multiplier phototube indicates that for an analyzer always to have a resolution consistent with that of a scintillation counter, the window widths should increase in proportion to the square root of the amplitude level.

Other particle detectors, such as the proportional counter or the ion chamber, can also be described by statistical characteristics. Although the sensitivities of these devices are much lower than that of a scintillation detector, their amplitude resolutions—assuming reasonable experimental precautions—are considerably better.

Earlier articles in this series have mentioned requirements on speed and resolving time of an analysis system. The investment in a complex multichannel analyzer is justified by its ability to process a large amount of information in a short time. This capacity is increased both with the number of channels and with decreased resolving time.

Analyzers capable of counting rates of the order of 10,000 cps (corresponding to resolving times of 5 μsec or less) can accumulate data of high statistical accuracy within a few minutes, thereby making possible a saving of many man-hours per week. Particularly in coincidence experiments, high counting-rate capability is important if astronomically long counting intervals —with resultant long-term drift problems—are to be avoided.

In the use of multichannel analyzers to obtain data of high statistical accuracy, the elimination of error due to relative drifts in channel boundaries is important. The threshold levels of a stable electronic discriminator, for example, can be held within 20 mv, so

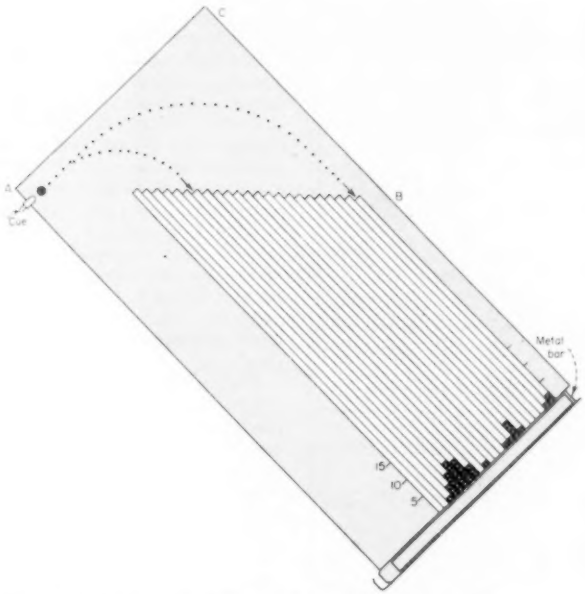

FIG. 21. Pictorial diagram of mechanical pulse-height analyzer (31)

that for 1% window stability, the window width should be no smaller than about 2 volts. Instability of window width is usually the most severe limitation on accuracy of results. Consequently, if the window stability is 1%, for example, it would be inconsistent to count for an interval longer than that required to reduce the statistical error much below 1%.

Mechanical Kicksorter

A 30-channel mechanical pulse-height analyzer (*31*), whose very nature describes graphically the pulse-amplitude analysis problem, is portrayed in Fig. 21.* Designed in an effort to obtain a reliability greater than that of usual complicated electronic analyzers, it is fundamentally very slow in operation and finds application in experiments where maximum counting rates are low. The basic structure consists of a plane inclined at about 10 degrees, in which are milled a series of 30 parallel, equispaced grooves.

Each voltage pulse causes a steel ball to be ejected from a launching site with an initial energy proportional to pulse amplitude, so that the ball, after describing a parabolic trajectory, will be collected in the appropriate groove. After a period of time, balls accumulate in columns, the tops of which portray the amplitude-distribution histogram.

The balls are "fired" by an electronic "billiard cue" constructed similarly to the voice coil in a dynamic loudspeaker. Input voltage pulses are processed in an electronic presorter which amplifies and lengthens the pulses to 100 μsec. Discriminator circuits then select pulses having amplitudes lying between limits corresponding to the first and last grooves of the analyzer. A final pulse amplifier drives the billiard cue and simultaneously initiates a dead time of approximately 0.15 sec, so that the next pulse cannot arrive before the feeder has loaded a new ball in position.

The feeder consists of a simple electromagnetic escape device which allows one ball at a time to drop into the firing position immediately after a predecessor has been expelled. The billiard cue, which imparts to the ball a velocity proportional to its own precollision value, receives from the driving coil an acceleration proportional to the input-pulse amplitude. Its terminal velocity is, therefore, proportional to the square root of pulse amplitude, and the initial energy of the steel ball—proportional to the square of velocity—is thus commensurate with pulse amplitude.

In its present form, this mechanical analyzer has a storage capacity of 100 balls in each of 30 channels. Its maximum speed is about 6 per second. The level drift is certainly less than one window width; amplitude resolution is such that with monoenergetic input pulses, approximately 85% of the balls fall in the proper channel; the remaining 15% are divided about equally between the two adjacent channels.

Diode Discriminator

A series of three pulse-height-analyzer designs using thermionic-diode discrimination has evolved during the last 6 years. Of these three analyzers, each of which contains a cascaded sequence of channel-defining discriminators followed by anticoincidence circuits, the first two (*32, 33*) are reasonably complex, but even so, are incapable of the higher counting rates and shorter resolving times demanded today. The third (*5, 34*), a well-engineered and more recent design,† is a six-channel instrument which can be operated with other identical units to provide 60-channel resolution.

Basically, this instrument consists of a gain-of-five wide-band, linear driver-amplifier which expands the 40-volt input spectrum to a range of 200 volts, followed by a series of six cascaded diode discriminators, amplifiers, and anticoincidence circuits. The output circuit at each channel is connected to a fast decade scaler and register.

A schematic diagram for the driver amplifier is shown in Fig. 22. Tubes V_1 and V_2 form a stable gain-of-five feedback amplifier, from which a negative output signal, at the plate of V_2, drives a White, or stacked, cathode follower. This circuit, containing tubes V_3 and V_4, has a gain of nearly unity and an output impedance of only a few ohms. From the plate of V_4, a negative signal of 200 volts maximum

* Figures 1–11 appeared in Part I of this article (NU, July '52, p. 20), and Figs. 12–20 appeared in Part II (NU, Aug. '52, p. 22).

† Manufactured commercially by the Canadian Marconi Co., Montreal, Canada, and distributed in the U. S. by Atomic Instrument Co., Cambridge, Mass.

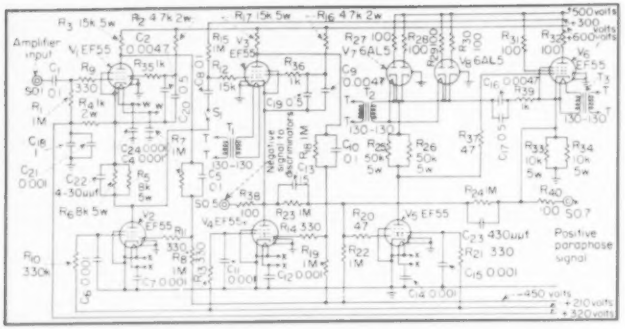

FIG. 22. Driver-amplifier unit of six-channel analyzer (5)

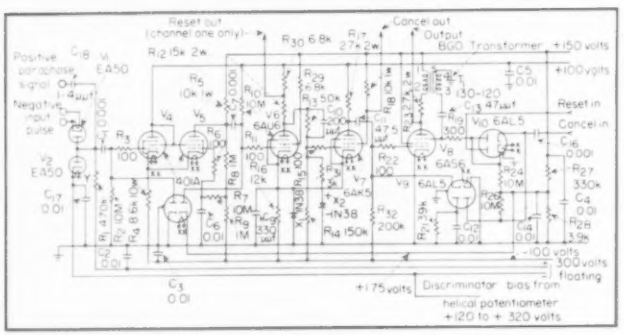

FIG. 23. Discriminator and anticoincidence circuit of six-channel analyzer (5)

amplitude feeds a group of six diode discriminators.

A paraphase neutralizing signal, obtained by inverting the discriminator input signal with a gain-of-minus-one feedback amplifier, is used to cancel the effect of capacitive coupling in the diode discriminators. In this circuit, tubes V_3 and V_4 form a series-connected amplifier stage (*22*). Because of the boot-strap connection from the cathode of V_4 to the top of the load resistance for V_3, this load resistance appears dynamically to be very large. A loop gain approaching $\mu/3$ can thus be realized; μ is the amplification factor of V_3. Diodes V_2 and V_8 provide quiescent current for V_3, and restore the charge on C_{16} and C_{17} after the occurrence of a pulse.

In the diagram of Fig. 23, which shows a discriminator and anticoincidence circuit for one channel, tube V_1 constitutes the amplitude-selecting element. Capacitor C_{18} is adjusted for optimum cancellation of signals coupled through the diode capacitance. Diode V_2 is so connected that any variation in discrimination level due to a change in the heater potential of V_1 is canceled by a similar effect in V_2; these diodes are installed as matched pairs.

Discrimination bias from a helical potentiometer is applied to the cathode of V_2. To avoid any change in quiescent forward voltage drop across V_2 due to a change in discriminator bias, the current through this tube is held constant at 0.6 ma by the use of a floating 300-volt supply. Diode V_3 prevents positive base-line overshoot at the end of a pulse.

Any pulse tops passed by the diode discriminator are observed by a subsequent discriminator, V_6-V_7, with preamplifier, V_4-V_5—having an effective input bias of 0.2 volt. Note that the d-c feedback from plate to grid of V_5 provides operating-point stabilization. The input tube, V_6, of the Schmitt circuit conducts normally; a pulse top sufficiently large will transfer current from V_6 to V_7.

For correct classification, a diode-and-capacitor combination, X_2-C_{10}, provides for a minimum triggered interval of 2 μsec. The square waveform at the plate of V_7, differentiated, delivers at the trailing edge a positive pip to coincidence tube V_8. The suppressor grid of V_8 receives negative pulses from the screen grid of V_7 in the next higher channel. If V_7 in this higher channel has not been triggered, no cancel-in pulse is present, and the positive spike from V_7 will generate, by blocking-grid action, a negative output signal.

If a cancel-in pulse drives the suppressor grid negative, V_8 cannot generate an output signal. To insure time coincidence (see Part II), diode V_{10} permits capacitor C_{13} to retain the cancel-in pulse until the arrival of a reset signal, which removes the stored cancel-in pulse and readies the circuits for a subsequent input signal. The reset signal is generated in a reset unit (not shown) which inverts and delays for 5 μsec the trailing edge of the positive pulse at the plate of V_6.

An output from the plate of V_8 triggers a fast decade scaler, which in turn drives an electromechanical register. The analyzer is capable of a maximum sustained counting rate per channel of 50 cps, or a maximum rate at peaks of 150 per second. These rates can be increased with an additional cascaded scaler in each channel.

This flexible six-channel instrument has window boundaries which are continuously and accurately adjustable by individual helical potentiometers over a range from zero to 200 volts, and which are individually stable to within 0.1 volt. The analyzer can accommodate input pulses having a maximum duration of 600 μsec and a minimum spacing of 10 μsec.

As discussed in Part I, crystal-diode discriminators have not replaced thermionic diodes because of problems arising from their smaller reverse-to-forward-resistance ratio, and lower inverse-voltage rating. A 10-channel analyzer using crystal-diode discriminators has, however, been constructed (*55*) and is providing satisfactory performance.

Schmitt-Circuit Discriminator

A 10-channel pulse-amplitude analyzer employing a lock-in type of Schmitt trigger circuit as discriminator

element to define the window boundaries has been described by Elmore and Sands (*6*, *7*). An input pulse of arbitrary amplitude triggers all lock-in discriminators of level lower than the pulse amplitude. Because of the lock-in feature, these circuits remain triggered after the disappearance of the input pulse. Several microseconds later, a registering pulse interrogates adjacent discriminators for anticoincidence and feeds an output signal to the scaler of the appropriate channel. A reset pulse, generated $1\frac{1}{2}$ μsec thereafter, then returns all pulse-height selectors to the quiescent state. Counts are registered in 10 channels; excess and total counts are indicated.

Bias potentials from a voltage-divider chain of wire-wound resistors define the window boundaries, which are adjustable for separations of 2, 5, or 10 volts. Due to drifts in "contact potential" and other causes, the actual window widths can fluctuate as much as 0.4 volts—20% of a 2-volt channel.

The minimum time resolution of the system is approximately 5 μsec; however, in any one channel, the combination of the scale-of-8 divider and register limits the channel counting rate to 100 per second, if a 0.1% loss due to overlap is not to be exceeded.

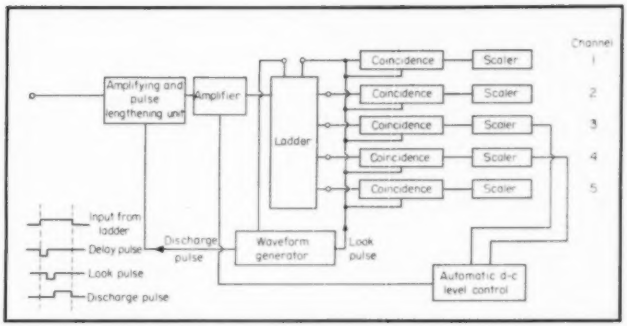

FIG. 24. Block diagram of sorting-ladder analyzer (36)

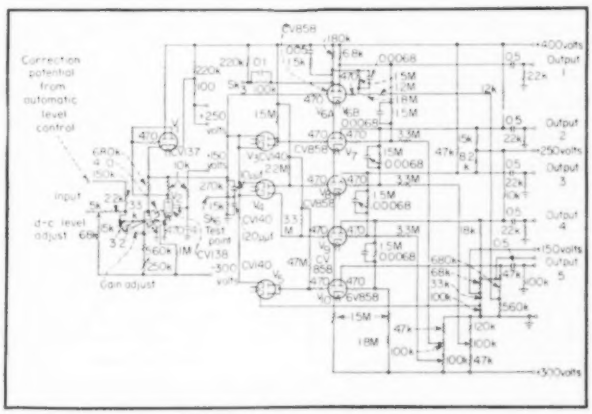

FIG. 25. Sorting unit of sorting-ladder analyzer (36)

Sorting Ladder

A unique and versatile pulse-height analyzer, developed by Cooke-Yarborough and others (*36*), is based upon a circuit known as a sorting ladder. A block diagram for the entire analyzer is shown in Fig. 24. In a prebiased amplifying and pulse-lengthening unit, that portion of each input pulse exceeding a given level is amplified and lengthened to obtain a flat-topped signal.

Pulse lengthening is accomplished by charging a storage capacitor through a diode to the peak value of the pulse. The capacitor remains charged until after the sorting process, when a discharge pulse from the waveform generator removes the stored charge. The lengthened input pulse so formed is delivered to the sorting unit where it is further amplified and then classified.

A schematic diagram for the sorter unit is shown in Fig. 25. Tubes V_1 and V_2 constitute a series-connected pulse amplifier with voltage feedback which amplifies the previously selected portion of the input amplitude spectrum.

Negative output pulses of 330 volts maximum amplitude are coupled directly to the grid of V_{6A} and through dual diodes V_3, V_4, and V_5 to the remaining input grids of the sorting ladder. This ladder is composed of five dual triodes, V_6–V_{10}, with the left triode of each pair connected in series between +400 and −300 volts. Quiescently, the grid of each of these triodes is held at cathode potential by grid current through a resistance connected to the positive supply. Consequently, each plate of the four coupling diodes is biased to a successively lower potential.

The right-half triodes are normally cut off; each plate is connected through a load resistance to a potential appropriate to the tube's position on the ladder. A sufficiently large negative input signal cuts off V_{6A}. Because of the resistive coupling from the plate of V_{6A} to the grid of V_{6B}, conduction shifts regeneratively to V_{6B}, and a negative signal is produced at its plate. Similarly, if the input pulse goes still further negative, a current transfer occurs in one or more of the lower dual triodes. Thus, when the left half of any dual triode cuts off, current in all double triodes above it ceases. Consequently, the electron current flowing upward in the ladder is switched to one of six plate circuits depending upon the input-pulse amplitude.

A negative output signal for a scaler is obtained from that channel in whose range the input-signal amplitude falls. Channel widths of 50 volts are utilized; in this manner reasonable threshold drifts of 0.5 volts, or less, will produce

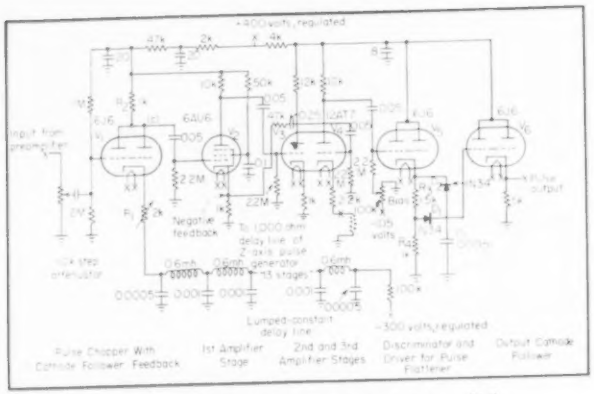
+400 volts, regulated
Input from preamplifier
Negative feedback
To 1,000 ohm delay line of Z-axis pulse generator (3 stages)
-105 volts
-300 volts, regulated
Lumped-constant delay line
Pulse Chopper With Cathode Follower Feedback
1st Amplifier Stage
2nd and 3rd Amplifier Stages
Discriminator and Driver for Pulse Flattener
Output Cathode Follower

FIG. 26. Pulse-shaping unit of Glenn beam-deflection analyzer (25)

no more than 1% drift in window width.

Spurious responses due to the rise and fall of the lengthened input pulse through the channels are suppressed by incorporating in each channel a resistive coincidence circuit (not shown) which transmits a signal to the following decade scaler only when permitted by the presence of a "look" pulse from the waveform generator.

The scaler consists of a flip-flop which drives a ring-of-five counter circuit using triggered neon tubes. An automatic d-c leveling device can be used to compare, in a relay counting circuit, the number of pulses in two adjacent channels, and to center these channels on a desired peak of a distribution curve. Feeding a direct correction potential from this difference unit to the sorting-ladder driving amplifier provides centering action.

The amplifying and analyzing circuits are direct-coupled throughout. Variations in base-line level due to the random nature of input pulses can arise only from a-c coupling in circuits preceding the analyzer.

Results of drift tests indicate an input drift of less than 30 mv, including the effect of a 10% change in line voltage. (At maximum gain, five channels appear at the input to occupy about 10 volts.) Use of the level-centering unit reduces the drift to a negligible value. Random shifts in window thresholds alter window widths less than 1%.

Because of the relatively long duration of the look and discharge pulses, the resolving time of the analyzer, exclusive of scalers, is of the order of 50 μsec. Deionizing time of the neon tubes limits the random counting rate in any one channel to 2,000 per minute if a 1% counting loss is not to be exceeded.

Beam Deflection

A number of pulse-height analyzers using a beam-deflection tube as discriminating element have been developed during the past several years. Such a beam-deflection tube is a cathode-ray tube having a number of target, or collector, electrodes, mounted in line across the end of the tube.

A flattened input pulse applied to a pair of deflection plates sweeps the normally off beam to an electrode of location comparable to pulse amplitude. During the flat pulse top, the beam is gated on, and a quantity of charge is deposited on the electrode. The signal so produced causes another count to be inserted into the scaler-register combination for that channel.

Some design problems involved in such an analyzer are the geometrical construction of the collector-electrode assembly to obtain equal channel widths, the procurement of a sharply defined electron beam for high channel resolution, the proper utilization of the low-level output signal obtained from a collector electrode, and either the elimination, or the utilization, of secondary-emission currents created by the bombardment of a collector electrode by the cathode-ray beam.

The charge pulse deposited on a collector electrode is insufficient to drive the scaler or register directly; it is usually amplified in a stable amplifier. Since the relation between charge collected by a target as a function of beam position is not discontinuous at the electrode edge, the apparent location of the edge will be determined in part by the amount of gain following the collector electrode and by the scaler or register threshold. A discriminator having an adjustable threshold is frequently located between the target electrode and the register-driver amplifier to control more effectively this apparent location of electrode boundary. The output-amplifier gain or discriminator threshold is usually adjusted so that the electrical boundaries of adjacent dynodes merge, providing a negligible gap or overlap between channels. Note that this use of a beam-deflection tube obviates the need for anticoincidence circuits.

An early beam-deflection analyzer built by Glenn (25) utilizes a continuously pumped, laboratory-constructed cathode-ray tube having 50 copper collector electrodes aligned on a Lucite face plate. These targets are coated with Aquadag to minimize the effects of secondary emission.

The input pulse, clipped by a delay line, is amplified and passed through a nonlinear circuit which flattens the pulse top. A 22-μsec signal results, which deflects the beam through an angle proportional to pulse height. A schematic diagram for the pulse-shaping amplifier is shown in Fig. 26. Note the differentiating circuit comprising tube V_1 and lumped-constant delay line D_0, feedback amplifier V_2–V_3, and pulse flattener V_4. In this pulse-flattener circuit, capacitor C_1 is charged by the rising portion of the pulse through diode D_1 to the potential at point A. During the falling portion of the pulse, diode D_1 opens, and the charge on C_1 is retained until the potential at B falls below that of C_1, causing diode D_2 to conduct and C_1 to be discharged. As a result, the output pulse is flat-topped and has a height proportional to that of the input signal.

A Z-axis pulse generator gates on the 0.3-μa beam of the deflection tube for 5 μsec, thereby depositing a charge of 1.5 micromicrocoulombs on the appropriate dynode. This charge develops a voltage pulse across the low input capacitance, which pulse, strengthened in a three-stage amplifier, drives an

electromechanical register. The sensitivity control in the driver stage of this amplifier can be adjusted so that the counting threshold occurs at any desired fraction of the normal signal amplitude.

The resolving time of the analyzer proper, limited mainly by pulse length, is approximately 35 μsec. Any one channel is limited in speed by the electromechanical register to a rate of 120 pulses per second.

A more recent model by Glenn (*26*) utilizes a commercially constructed 10-channel pulse-analyzer tube (DuMont K1059) in which resolution is enhanced by thin partitions, or shields, separating the 10 collector electrodes. An illuminated collector electrode receives either the full beam current directly, or else an equal current of secondary electrons from the shield. Pulse-shaping and beam-gating circuits in this analyzer are similar to those in the earlier model.

A diagram of the pulse-analyzer tube and channel-amplifier circuits is shown in Fig. 27. With an increased beam current of 200 μa, the output-amplifier design can be simpler; it consists of a univibrator discriminator followed by a pulse lengthener and a register-driver tube. Provision is made in the channel amplifiers for inserting a scaler ahead of the register driver when high counting rates exist. When the univibrator is adjusted to trip at 50% of maximum signal, the channel overlap or gap is $\leq 2\%$.

Other performance characteristics, including resolving time, are similar to those of the earlier system. The main amplifier unit, which includes the pulse amplifier and lengthener as well as the deflection and gating amplifiers, requires 14 tubes, exclusive of power supply. Each channel amplifier utilizes but $2\frac{1}{2}$ tubes, not including the scaler.

Glenn (*26*) has described a unique analysis system using a 10-channel beam-deflection tube preceded by five diode discriminators to obtain 60-channel information. If the top of an input pulse, for example, lies between the levels of diodes 2 and 3, the bias potential for diode 2 is subtracted from the pulse, and the excess is measured by the beam-deflection tube. Thus, the diodes can be said to determine the tens digit of pulse-height, and the cathode-ray tube the units digit.

A ten-channel electrostatic-deflection analyzer developed by Weiss (*37*) and Watkins (*27*) utilizes a tube having a line-focused beam. The block diagram of Fig. 28 indicates that an input pulse is lengthened to 3 μsec and that, during this interval, the cathode-ray beam is turned on for 1.5 μsec. Each of the 10 output amplifiers contains two cascaded triode-amplifier stages, and a cathode follower to drive the subsequent scaler. The discrimination control on each scaler makes possible adjustment for equal channel widths.

A diagram for the deflection-tube circuit is shown in Fig. 29. The target potentials are set at a value somewhat lower than that of the anode (300 volts) to obtain maximum secondary emission. With a target current of at least 100 μa, each pulse causes the beam to deposit about 150 micromicrocoulombs on the appropriate collector.

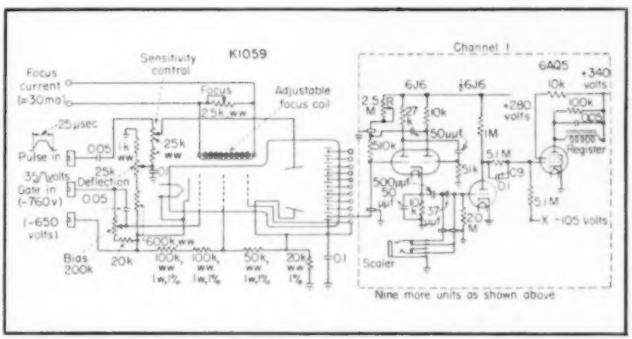

FIG. 27. Pulse-analyzer tube and channel-amplifier circuits of Glenn beam-deflection analyzer (26)

Operating potentials for the entire analyzer are obtained from regulated power supplies. Watkins (*27*) states that the stability is such that, once the system is adjusted, no measurable change in calibration can be detected. The counting rate is limited by register resolving time. For a uniform spectrum, 1% statistical loss occurs at an input rate of 250 cps.

As constructed, the analyzer requires an input-pulse rise time of 1 μsec or less; with different delay lines, longer rise times are permissible.

Since any circuit which receives the target output from a beam-deflection tube will exhibit some discriminatory characteristics, one might question the value of the beam-deflection arrangement, and ask why the voltage pulse to the deflection electrodes might not be more advantageously applied directly to the discriminator circuits themselves. One argument in favor of the beam-deflection tube is that it obviates the need for anticoincidence circuits.

Kelley (*30*) has remarked that a dynode beam-deflection tube driving discriminators can be considered as a special kind of expander amplifier (see Part II) which may improve the overall system stability to the extent that "its gain advantage overcomes its instability" through a reduction in the fractional window-width change caused by a variation in discrimination level.

The incremental gain characteristic of a beam-deflection tube is partly explained by the diagram of Fig. 30, in which the target current, i_t, of a collector electrode is plotted as a function of beam-deflection potential, e_d, i.e., as a function of beam position. As the electron beam strikes more and more of the collector, the target current increases until the full beam current is received by the collector. Clearly, the smaller the beam diameter, the steeper the sides of the current-voltage characteristic. The incremental transconductance, g_m, of the deflection tube at the threshold is thus proportional to the product of beam current, i_{beam}, and the number of spot diameters, n_{sp}, through which the beam is swept by unit deflecting potential, so that $g_m = k\, i_{beam}\, n_{sp}$, where k is a constant of proportionality. (The deflection sensitivity of the tube is contained in the quantity n_{sp}.)

Connected to the target is a circuit

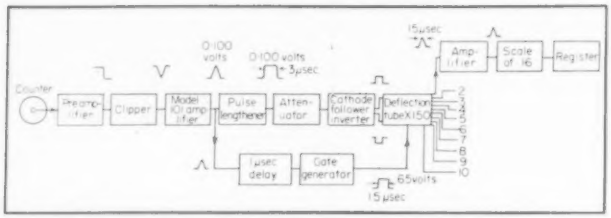

FIG. 28. Block diagram of Watkins beam-deflection analyzer (27)

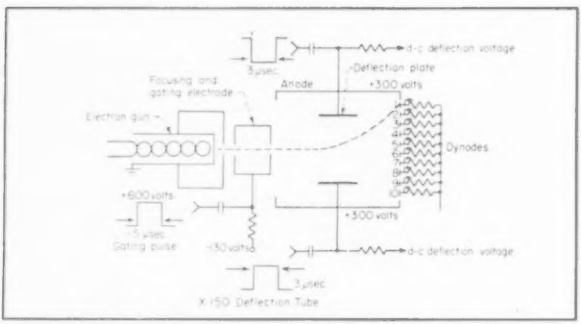

FIG. 29. Deflection-tube circuit of Watkins beam-deflection analyzer (27)

consisting of the input resistance of the channel amplifier in parallel with a parasitic capacitance, C. The time constant of this circuit is, in practice, at least several microseconds, so that reasonably short bursts of beam current, of duration δ, are integrated. Hence, the incremental preamplifier gain, K, from deflection potential e_d to target potential e_t, becomes

$$K = k\, i_{beam}\, n_{sp} \frac{\delta}{C} \qquad (16)^*$$

For a pentode, one can define a gain-bandwidth product (or gain-rise-time quotient) proportional to g_m/C. Similarly, a beam-deflection tube can be characterized by a gain-bandwidth product proportional to $i_{beam}\, n_{sp}/C$. In fact, the use of a beam-deflection tube as a high-gain × bandwidth element in fast trigger circuits and other devices is currently being investigated.

The beam-deflection tube may thus be considered as a preamplifier which drives a subsequent discriminator. To evaluate the increase in stability of window width, if any, the concepts expressed in Eqs. 13 and 14 (Part I) may be used. If one considers the behavior of the system at an arbitrary target, e_s is the threshold of the complete discriminator with the deflection-tube preamplifier, e_1 the threshold of the deflection tube only, and e_2 the threshold of the subsequent discriminator only. Thus,

$$e_s = e_1 + \frac{e_2}{K} \qquad (13)$$

$$\Delta e_s \cong \Delta e_1 + \frac{\Delta e_2}{K} + \left(\frac{\Delta K}{K}\right)\frac{e_2}{K} \qquad (14)$$

If the net variation in threshold is to be a smaller fraction of window width, the ratio of drift in e_s to that in e_2, $\Delta e_s/\Delta e_2$, must be smaller than the gain factor. The relationship between $\Delta e_s/\Delta e_2$ and K thus becomes a measure of advantage to be gained through use of a beam-deflection tube.

Drift in e_1 may arise from changes in supply potentials, structural changes in the electron gun due to temperature, the accumulation of stray charges on the tube walls, etc. Drift in K may be caused by decreasing cathode emission, variations in amplitude of the beam-gating signal, changes in supply potential (particularly accelerating potential), etc. Because of the many possibilities for increased drift, many experimenters do not consider use of beam-deflection tubes justified now.

Considerable effort has been and is being expended to improve the performance of these beam-deflection tubes. The 10-channel tube used by Watkins (*27*) had a sensitivity of approximately $^2/_3$ spot diameter per volt, and a beam current of 100 μa. A British study (*38*) on the other hand, predicted a tube having a sensitivity of 4 diameters per volt, and a current of 10 μa. More recently, tubes have been built with a sensitivity of 5 diameters per volt, and a beam current exceeding 100 μa (*39*); an electron gun with a sensitivity of 9 diameters per volt has been reported. Utilization of these and other improved beam-deflection tubes may result in analyzers of increased stability and resolution.

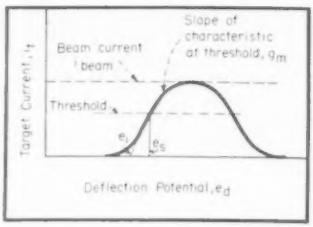

FIG. 30. Input-output characteristics of a beam-deflection tube

BIBLIOGRAPHY

NOTE: References 1–16 appeared in Part I of this article, and 17–29 appeared in Part II.

30. G. Kelley, NUCLEONICS **10**, No. 4, 34 (1952)
31. S. G. G. Frank, O. R. Frisch, G. G. Scarrott, *Phil. Mag.* **42**, 603 (1951)
32. W. F. Freundlich, E. P. Hincks, W. J. Ozeroff, *Rev. Sci. Instr.* **18**, 90 (1947)
33. C. H. Westcott, G. C. Hanna, *Rev. Sci. Instr.* **20**, 181 (1949)
34. "Pulse-Amplitude Analyzer," Bulletin NI-2011 (Canadian Marconi Co., Montreal, Canada, 1949)
35. V. Fitch, private communication
36. E. H. Cooke-Yarborough *et al.*, *J. Inst. Elec. Engrs. (London)* **97, III**, 108 (1950)
37. H. G. Weiss, AECD-3314 (1948)
38. E. W. Titterton, G/R-620 (Atomic Energy Research Establishment, Harwell, Engr., 1950)
39. G. A. Morton, Quarterly Report, (RCA Laboratories, Inc., Jan.–April, 1951)

NEXT IN THIS SERIES . . .

will be an article on
Multichannel analyzers—II
in October.
The first in the series were on
Voltage discriminators
Single-channel differential analyzers
and appeared in July and August

* Equations 1–15 appeared in Part I.

Electronic Structure of the Heaviest Elements

A revision of the "actinide hypothesis" is indicated by the review of magneto-chemical data made available since 1949. On the basis of ionic properties, Th, Pa, and U resemble elements of Groups IV, V, and VI in the periodic table

TABLE 1—Correlation of Lanthanide and Actinide Series (5)

Actinides		*Lanthanides*	
89-Ac	$6d7s^2$	57-La	$5d6s^2$
90-Th	$6d^27s^2$ (or $5f6d7s^2$)	58-Ce	$4f^26s^2$
91-Pa	$5f^26d7s^2$ (or $5f6d^27s^2$)	59-Pr	$4f^36s^2$
92-U	$5f^36d7s^2$	60-Nd	$4f^46s^2$
93-Np	$5f^47s^2$ (or $5f^46d7s^2$)	61-Pm	$4f^56s^2$
94-Pu	$5f^67s^2$ (or $5f^56d7s^2$)	62-Sm	$4f^66s^2$
95-Am	$5f^77s^2$	63-Eu	$4f^76s^2$
96-Cm	$5f^76d7s^2$	64-Gd	$4f^75d6s^2$

By J. K. DAWSON

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PRIOR TO THE DISCOVERY of the synthetic transuranium elements and the intensive study of their properties during the past few years, it was recognized that many chemical properties of thorium and uranium resembled those of zirconium and wolfram, respectively. It became the custom to place them under these sixth-period transition elements in the periodic table and to assign their unpaired electrons to the *6d* energy level.

However, a considerable number of investigators, beginning with Bohr in 1923 (*1*), has predicted theoretically that a series of elements could exist in which electrons might be assigned to the *5f* level. These elements would have properties similar to those of the lanthanide series in which the *4f* level is in the process of being filled.

Opinions differed as to where this new series should begin, the suggestions ranging from $Z = 90$ (*2*), thorium, to $Z = 95$ (*3*), the then hypothetical americium. Seaborg, having reviewed the early theoretical work and assembled the vast amount of data accumulated in the Manhatten Project (*4*), has postulated the well-known "actinide hypothesis" (*5*). His suggested electron configurations are shown in Table 1.

There seems little doubt that in the region of atomic numbers 95 and 96 the actinide hypothesis accounts for many of the observed properties. By its use it was possible to devise procedures for the isolation of elements 97 and 98 (*6*). Seaborg, however, extrapolated back from this data and suggested that *5f* electrons may be present as early in the series as thorium.

The magnetic behaviour of *f*- and *d*-shell electrons in lower regions of the periodic table is quite different, so that measurements of the magnetic susceptibilities of compounds of these heaviest elements should give information on the energy levels of their unpaired electrons. The information on magnetic properties made available since 1949 indicates a scheme of configurations differing from Seaborg's.

Paramagnetic Theory

The main differences between the magnetic behavior to be expected of *d*- and *f*-shell electrons will be described before discussing empirical results.

Any atom, or ion, having an odd number of extranuclear electrons, or not having all the electrons paired, has a permanent magnetic moment which is capable of orientation on the application of an external magnetic field—such atoms are said to be paramagnetic. Those not having a permanent magnetic moment are termed diamagnetic.

The classical theory of paramagnetism was developed by Langevin on the assumption that each atom behaves as a small permanent magnet and that these atomic magnets tend to become aligned parallel to an applied magnetic field. This alignment is opposed by thermal agitation. Langevin's expression is $x = N\cdot\mu^2/3kT$ where x is the

gram-ionic susceptibility, μ is the permanent magnetic moment, and N is Avogadro's number. This expression, since it takes no account of interaction between neighboring ions, really applies only to the ideal gaseous state. It represents the behavior of a fair number of compounds.

The relationship $x = C/T$, known as Curie's law, was discovered experimentally by Curie prior to Langevin's work. More accurate and extensive work since that time has shown that the behavior of many more compounds may be represented by the Weiss modification, $x = C/(T + \Delta)$.

The magnetic moment of an ion may be regarded as being composed of two parts—a contribution from the orbital motion of the unpaired electrons and another contribution from their spins. The Weiss constant, Δ, usually arises from two causes:

1. A quenching effect of electric fields produced by neighboring ions on the orbital contribution to the moment.

2. The Heisenberg exchange interaction. When magnetic atoms or ions are very close together, this interaction has the effect of introducing a strong coupling between the spins of their respective unpaired electrons. Since this interaction cannot take place between paired (diamagnetic) electrons, dilution of a solid compound with one which is isomorphous and diamagnetic leads to a diminution of the effect and the observed susceptibility becomes much closer to that expected for free gaseous ions.

The electron configuration of the lanthanide elements has been shown to be . . . $4f^{n}\,5s^{2}5p^{6}5d^{0}6s^{2}$, the characteristic trivalent ions having lost the $6s$ and the $5d$ electrons to leave the $4f$ electrons, which are responsible for the paramagnetism, shielded to a great extent from external influence by the $5s$ and $5p$ electrons. Consequently, the magnetic behavior of these trivalent ions is a near approximation to the free gaseous state.

About 1925, Hund predicted the spectroscopic ground states and the magnetic moments of the lanthanides by using the Pauli exclusion principle, assuming that the lowest energy is possessed by the spectral term of highest multiplicity and that the electrons are in Russell-Saunders or L–S coupling (7). Thus, in an ion with more than one unpaired electron, the spin vectors of the electrons combine to give a resultant spin vector, and similarly with the orbital vectors. The resultant vectors then combine to form the total moment, J. Hund's formula for the magnetic moment is $\mu = g\sqrt{J(J+1)}$, which may be substituted in the Langevin expression to give a theoretical value

$$x_m = N g^2 \beta^2 J(J+1)/3kT$$

The Landé splitting factor, g, is computed from the quantum numbers of the lowest energy state

$$g = 1 + \frac{S(S+1) + J(J+1) - L(L+1)}{2J(J+1)}$$

Hund's predictions (which assumed no ionic interaction) agreed well with experimentally determined moments, with the exception of samarium and europium. The behavior of these two elements has been clarified in a more detailed study by Van Vleck (8), discussed later in connection with Pu(III).

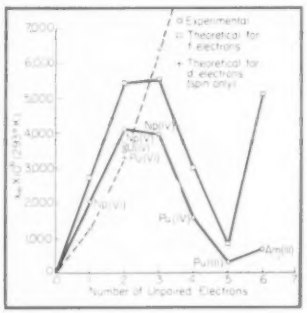

FIG. 1. Susceptibilities in solution

Even in the case of compounds of the lanthanides which are magnetically concentrated (the interionic distance is at a minimum and there is the greatest chance of interaction), the values of the Weiss constant, Δ, are comparatively low due to effective screening by the $5s$ and $5p$ electrons. The situation is quite different if we consider a series of transition elements —*e.g.*, scandium to manganese in which the first half of the $3d$ sub-shell is being filled. Their ions possess measured magnetic moments which may be represented by $\mu = 2\sqrt{S(S+1)}$. This expression, having the same form as Hund's formula, gives magnetic moments usually referred to as "spin-only." Since the $3d$ electrons of these ions are not screened like the $4f$ electrons of the lanthanides, there can be complete quenching of the orbital contribution to the moment.

The exchange forces between the d-shell electrons of neighboring ions may be sufficient to partially "quench" the spin contribution and may be so strong in magnetically concentrated compounds that they are indistinguishable from a metallic bond. The Weiss constant then often approaches infinity, and the susceptibility becomes independent of temperature. Moreover, the value of the susceptibility becomes very small because the spins of neighboring ions become aligned antiparallel, thus cancelling each other out. Compounds showing various degrees of this antiparallel alignment are classed as antiferromagnetic. The rigid alignment of the spins is always opposed by thermal agitation, and there is a temperature above which the spins are able to "break loose." This temperature, the antiferromagnetic Curie point, is usually associated with a specific heat anomaly. The behavior above the Curie point is similar to that of normal paramagnetic salts.

Broadly speaking, then, if compounds of the heaviest elements have magnetic susceptibilities close to the theoretically predicted spin-only values even in magnetically dilute systems, and if in more concentrated systems they exhibit effects due to strong ionic interaction, this may be interpreted as evidence in favor of d-shell electrons. But if the susceptibility behavior in dilute systems approximates that expected for the free gaseous state, this will be evidence for f-shell electrons. The technique of dilution with an isomorphous diamagnetic compound has been very useful in this respect since it allows an extrapolation of the magnetic properties to infinite dilution for comparison with the theoretical free gaseous state.

The interpretation is somewhat complicated, however, by the fact that the theoretical arguments apply to limiting cases. The actual susceptibilities may fall somewhere between them since the screening effect of possible $5f$ electrons by $6s$ and $6p$ electrons is expected to be considerably less than was observed with the $4f$ electrons, thus allowing *some* orbital quenching. The energy separation of the ground

state from the next lowest level may be small enough to allow some contribution to the magnetic susceptibility from the latter (Hund's predictions, discussed earlier, are based on the assumption that the multiplet splitting is wide compared to kT and that only the ground state contributes to the susceptibility).

Heaviest-Element Ion Solutions

The magnetic measurements of plutonium ions in solution, first reported in 1948 (*9*), were later extended by Howland and Calvin (*10*). They reported measurements on some ions of uranium, neptunium, plutonium and americium in aqueous solution. Their results are shown in Fig. 1 together with the corresponding theoretical limiting values for $5f$ electrons in L–S coupling and $6d$ electrons with complete orbital quenching. They claimed that the qualitative similarity between the curve for the heaviest elements and that for the lanthanides (which is almost exactly the same as the theoretical one for f electrons) is an indication that ions of the elements beyond uranium are members of a series with the outer electron configuration $5f^n6s^26p^6$, the unpaired $5f$ electrons being relatively shielded from external influence as in the case of the lanthanides. However, the first part of the curve could be said to follow the theoretical one for $6d$ electrons as closely as that for $5f$ electrons. Much more detailed investigations are necessary to deduce the real ground state configurations.

Solid compound studies, allowing measurements over much wider temperature ranges than are possible with aqueous solutions, can give evidence of the extent of ionic interaction, and, thus, more definitely identify the unpaired electrons.

One Unpaired Electron

From thorium's position in the periodic table, we might expect it to give rise to a quadrivalent ion with no unpaired electrons, a trivalent ion with one, and a divalent ion with two unpaired electrons. Thorium (IV) compounds, since they are diamagnetic and isomorphous with the corresponding U(IV) and Pu(IV) compounds, have been used for diluting the latter ions so that measurements can be made in crystal environments sufficiently dilute to eliminate exchange effects.

TABLE 2—Magnetic Susceptibility of Ions with One Unpaired Electron

Compound	$\chi_m \times 10^6$ *(corrected for diamagnetism)*	μ	*Reference*
VCl_4	1,230		(*14*)
VO_2	92		(*14*)
WCl_5	524		(*15*)
$MoCl_5$	879		(*15*)
	860		(*16*)
CeF_3	2,411		(*17*)
ThI_3	355		(*12*)
Np(VI) solution (sulphate)	2,060		(*10*)
$NaNpO_2(C_2H_3O_2)_2$	1,790	2.35 above 185° K 1.87 below 185° K	(*18*)
Theoretical (f^1 config.)	2,685	2.54	
Theoretical (d^1 config. spin-only)	1,245	1.73	
Theoretical (d^1 config. with full orbital contribution)	998	1.55	

Calvin has investigated the magnetic susceptibilities of thorium and uranium sulphides (*11*), which are of a semimetallic nature and magnetically very concentrated. He found, for instance, that Th_2S_3 is diamagnetic, and the author has observed that Th_2Se_3 is also slightly diamagnetic (*12*). These results may be compared with those on Ce_2S_3 (*13*). Both thorium and cerium should have the same number of electrons available in the outer shells. However, the paramagnetism of Ce_2S_3 indicates that there is one unpaired electron (presumably $5f$) whereas the results on Th_2S_3 and Th_2Se_3 show that all the electrons are paired. In fact, the exchange forces between neighboring thorium ions are so great that they amount to a metallic bond and the spin moments mutually cancel out. This would not have been expected if the normally unpaired electron were in the $5f$ energy level since ionic interaction should be relatively small owing to the shielding effect of the $6s$ and $6p$ electrons.

The magnetic susceptibilities at room temperature of various ions with one unpaired electron are compared in Table 2. In the magnetically concentrated VO_2, WCl_5 and $MoCl_5$, there are various amounts of ionic interaction leading to the formation of metallic bonds and a reduction of the spin contribution to the susceptibility. The susceptibility of ThI_3 is more comparable with these compounds than with CeF_3, a magnetically concentrated representative of the lanthanides. The amount of interionic exchange is again consistent with a d-shell configuration.

On the other hand, the results on the neptunyl ion appear to be more in agreement with the theoretical value for a $5f^1$ electron configuration, there being partial orbital quenching by the crystalline field or by solvent dipoles in the case of the solution. Below 185° K, however, the moment of sodium neptunyl acetate is closer to spin-only than to the $5f^1$ value.

A wider variety of results would appear to be very desirable, in particular on U(V). The results attained so far seem to indicate that the $5f$ and the $6d$ levels are very close in the ions with one unpaired electron. This is somewhat difficult to understand since the results on ions with two unpaired electrons show that the $6d$ level is considerably lower than the $5f$, which does not become definitely stabilized as the lowest level until there are four unpaired electrons available [see Pu(IV) below]. However, there is a close similarity with the deductions from spectroscopic data by DeBruin, Klinkenberg and Schuurmans (*19*) who claim that the gaseous ions Th(II) and Th(III) have ground states of $6d^2$ and $5f^1$, respectively.

Preliminary results on ThI_2, which should show evidence of two unpaired electrons, indicate that its susceptibility is very small. As in the case of ThS and ThSe, it would seem that

all the electrons are used up in metallic bonding (*12*). This would be expected only if the electrons are in the 6*d* level.

Two Unpaired Electrons

Of the possible ions of this series of elements which have two unpaired electrons, U(IV) has received the most attention. Early work by Sucksmith (*16*) on uranium dioxide and tetrachloride was interpretated by him as indicating that the susceptibility arose from a spin-only moment. Lawrence's results (*20*) on uranous perchlorate, sulphate and chloride in aqueous solution showed effective magnetic moments of about 2.95 Bohr magnetons, a value close to the theoretical spin-only moment of 2.83 for two unpaired electrons.

Uranium dioxide has recently been the subject of more extensive investigation (*21, 22, 23*). Its magnetic moment lies between the theoretical spin-only and $5f^2$ values. Without dilution experiments, this could be taken as evidence that the electron configuration is $5f^2$ and that there is partial quenching of the orbital part of the moment [the same remark applies to the other U(IV) compounds, see Table 2]. However, the moment is complicated by the inclusion of the Weiss constant, $\mu = 2.83\sqrt{x_m \cdot (T + \Delta)}$.

A more direct comparison with theory can be made by means of the susceptibility. That of the uranous ion in UO_2 is lower than in any other uranous compound. Dilution with isomorphous, diamagnetic ThO_2 shows that at infinite dilution the extrapolated susceptibility is quite close to the value expected from the spin-only moment of two unpaired electrons. This would most probably arise if the electrons occupied 6*d* orbitals since 5*f* orbitals would be expected to give a result nearer the free-gaseous-ion value. The very low susceptibility in pure UO_2 and the fall of the magnetic moment from 3.20 Bohr magnetons to 3.00 at infinite dilution have not been satisfactorily explained as yet, although they may possibly be connected with the covalent bonding which Zachariasen has suggested (*24*).

Uranium tetrafluoride is truly ionic (Zachariasen, *loc. cit.*). The susceptibility is considerably higher than that of the dioxide and is close to the theoretical spin-only value (*23, 25, 26*). Solid solution dilution in ThF_4 shows that the susceptibility is practically independent of concentration and that it is still very close to the spin-only value when extrapolated to infinite dilution, indicating *d* orbitals.

Sacconi has reported on a considerable number of S-coordinate complexes of U(IV) (*27*). The magnetic susceptibilities are all close to the spin-only value. However, he considers that the electrons are in 5*f* orbitals since the presence of two 6*d* electrons would not be consistent with the molecular orbitals $d^4s\,p^3$, d^3p^3 and $d^3s\,p^2$ proposed by Pauling (*28*) and Kimball (*29*) for S-coordinate complexes. On the other hand,* the assignment of two 6*d* electrons to U(IV) in these complexes (on the basis of the spin-only value of the susceptibility) might be evidence against the Pauling-Kimball orbitals and favor a cubic configuration involving 5*f* hybrid or-

TABLE 3— Magnetic Properties of Ions Having Two Unpaired Electrons

Compound	μ	Δ	$x_m \times 10^6$	*Crystal type*	*Reference*
Theoretical, $5f^2$ (L-S)	3.58		5,390		Hund
" $5f^2$ (jj)	3.81		6,140		Hund
" $6d^2$ (spin only)	2.83		3,333		Hund
UO_2	4.36	310	3,900	Cubic	(*16*)
	2.92	180	3,550		(*30*)
	3.20	233	2,416		(*21*)
	3.19	220	2,400		(*22*)
UO_2 (infinite dilution)	2.90		3,600		(*22*)
" " "	2.98	20	3,400		(*23*)
UF_4	3.30	147	3,040	Monoclinic	(*25*)
	3.30	102	3,411		(*23*)
UF_4 (infinite dilution)	2.86		3,370		(*23*)
UCl_4			4,080	Tetragonal	(*16*)
	2.7		3,820		(*31*)
	3.29	62	3,802		(*26*)
	3.14	39	3,636		(*31*)
UBr_4	3.12	35	3,709	Tetragonal(?)	(*26*)
K_2UF_6	3.45	108	3,643	(?)	(*25*)
	3.30	102	3,385	Cubic	(*25*)
KUF_5	3.30	122	3,222	Rhombohedral	(*25*)
$CaUF_6$	3.25	101	3,289	Hexagonal	(*25*)
Na_2UF_6	3.40	290	2,447	Tetragonal	(*25*)
US_2			3,050		(*11*)
Organic complexes of U(IV)	2.7-2.8		3,050-3,370		(*27*)
U(IV) in aqueous solution: perchlorate	2.95		3,633		(*20*)
U(IV) in aqueous solution: sulphate	2.95		3,643		(*20*)
U(IV) in aqueous solution: chloride	2.97		3,702		(*20*)
U(IV) in aqueous solution: chloride			3,690		(*10*)
$U(SO_4)_2 \cdot 4H_2O$			3,383		(*16*)
$U(SO_4)_2$			2,921		(*16*)
$U(SO_4)_2 \cdot 3.3H_2O$	3.52	113	3,810		(*32*)
$U(SO_4)_2 \cdot 4.2H_2O$	3.58	121	3,820		(*18*)
$U(C_2O_4)_2 \cdot 5H_2O$	3.75	168	3,750		(*32*)
$U(C_2O_4)_2 \cdot 6H_2O$	3.70	182	3,530		(*18*)
U(IV) acetyl acetonate	3.21	101	3,220		(*32*)
Np(V) solution (Cl^-)			4,120		(*10*)
Np(V) solution (ClO_4^-)	2.96	18	3,420		(*33*)
Pu(VI) solution	2.91		3,520		(*9*)
$NaPuO_2(C_2H_3O_2)_2$	2.82	0	3,305	Cubic	(*34*)
Pr_2O_3	3.55	55	4,478		(*30*)
VCl_3	2.89	35	3,150		(*14*)
VBr_3	2.72	20	2,910		(*14*)

* The author is indebted to Dr. J. S. Anderson and Mr. J. K. Perring for discussion on this point.

bitals with sufficient room for the unpaired electrons in the 6*d* level.

Table 3 lists the reported susceptibilities of a considerable number of uranous compounds together with observations on the other ions having two unpaired electrons, Pu(VI) and Np(V), and also with Pr(III) and V(III) for comparison. All the susceptibilities are corrected for the diamagnetism of the cation. Some are corrected also for the underlying diamagnetism of the anion. The temperatures of the observations vary over the range 293°–300° K, but the combined error due to this and to the variable diamagnetic correction is not greater than about ±2%. Where the moment only was quoted in the original papers, the susceptibility has been calculated taking into account the Weiss constant, and vice versa.

Except for the early results of Sucksmith on UO_2 and UCl_4 (which were possibly made on samples containing appreciable amounts of ferromagnetic impurity), the results for U(IV) lie almost entirely in the region 3,200–3,800 × 10^{-6}. The mean value is about 3,400 × 10^{-6}, quite close to the spin-only value and rather remote from the limiting theoretical value for a $5f^2$ configuration. Even in the magnetically concentrated oxide Pr_2O_3, the Pr(III) ion has a value very much nearer to the f^2 theoretical susceptibility. Comparison shows that uranous ion susceptibility is closer to that of the vanadium halides than to Pr_2O_3.

The plutonyl ion in sodium plutonyl acetate has an experimental magnetic susceptibility equal to the spin-only value (*34*). The susceptibility follows the Curie law between 90–330° K. The Weiss constant is zero. This indicates that the compound is magnetically very dilute and that the results may be compared directly with the theoretical values. These results are typical of electrons in *d*-shell orbitals. Similar arguments apply to results on NpO_2ClO_4 solution.

There is thus considerable evidence that the ions of the heaviest elements having two unpaired electrons show susceptibilities close to the spin-only value and that these electrons are consequently in the 6*d* energy level. The configuration appears to be stable enough to be unaltered by changes of crystal environment. It is interesting to note that recent low-temperature, heat-capacity measurements on UO_2 have been shown to give an anomaly at 28.6° K (*38*). This is similar to the anomalies found in MnF_2 and MnO and would seem to be further evidence for the electrons being in *d*-orbitals. In addition, if the plutonyl ion has a structure like that of the uranyl ion and its two unpaired electrons are in the 5*f* shell, then it would be expected to fluoresce like the lanthanide ions. In fact, it does not fluoresce (*39*), and this may be attributed to unpaired electrons in the 6*d* level rather than the 5*f*.

TABLE 4—Magnetic Susceptibilities at Room Temperature of U(III) Compounds

Compound	μ	Δ	$\chi \times 10^6$ *U(III)*	*Reference*
Theoretical $5f^3$ (L-S)	3.62		5,455	Hund
" $6d^3$ (spin-only)	3.87		6,250	Hund
U(III) solution (Cl^-)	3.22		4,335	(*20*)
U(III) solution (So_4^{2-})	3.17		4,215	(*20*)
UCl_3	3.03	−29	3,456	(*26*)
UBr_3	3.29	+25	4,896	(*26*)
UI_3	3.31	+5	4,673	(*26*)

Three Unpaired Electrons

There is a marked difference between the behavior of the trivalent halides and the quadrivalent halides of uranium (*26*). Dilution experiments on solid solutions have not been reported, but Lawrence has measured the susceptibility of aqueous solutions of uranium trichloride and sulphate. The results are summarized in Table 4.

It is evident that there is no general agreement with either of the limiting theoretical cases of $5f^3$ electrons in *L–S* coupling or the spin-only arrangement in a $6d^3$ configuration even in the aqueous solutions. The situation is more complicated than for the other ions in this series because there is only a small difference between the theoretically predicted susceptibilities and because, in the case of three unpaired electrons, the small energy separation of 5*f* and 6*d* energy levels suggests mixed population of the two levels.

Comparison with other ions shows that the room temperature susceptibility of UI_3 is almost exactly equal to those reported for Nd_2O_3 (*16*) and CrF_3 (*40*), both compounds having three unpaired electrons. Thus, there is little possibility of deducing the configuration of lowest energy by this means. Over the temperature range 90–400° K, the susceptibilities of both UBr_3 and UI_3 are quite close to that of Nd_2O_3, but the uranium compounds have positive Weiss constants and the susceptibility-temperature behavior follows a pattern similar to that found for a considerable number of antiferromagnetic ions of the *d*-shell elements. The curve of UCl_3 follows the results on VBr_2 (*14*) more closely than those on Nd_2O_3.

Thus we have qualitative evidence which might be attributed to either 6*d* or 5*f* electrons (or both). Without dilution experiments on solid solutions it does not seem possible to make any definite conclusions. Since it is expected that the energy differences between the 6*d* and the 5*f* levels will be small, it is quite possible that the observed electron configurations will vary from compound to compound.

Westrum, Hatcher, and Osborne have investigated the low-temperature heat capacity of NpO_2 (*41*). This should have three unpaired electrons, like U(III), and the measurements show a pronounced maximum in the heat capacity curve at 25° K. By analogy with similar phenomena in the manganese compounds, this suggests that it may be attributed to antiferromagnetism below 25° K. This would seem to be evidence for the electrons occupying 6*d* orbitals.

Before leaving the uranium salts, mention should be made of measurements which have been made on the element itself. Bommer found that the atomic susceptibility is about 620 × 10^{-6} and that there is a considerable dependence on temperature (*37*). More recently, Bates and Mallard have reported that between 20 and 350° C the atomic susceptibility (414 × 10^{-6} at room temperature) increases slowly with temperature. By comparison with similar behavior

by ruthenium, rhodium and iridium, they consider that the uranium should be treated as a transition-type element in which the unpaired electrons are in *d*-shell energy levels (*42*). Kriessman and McGuire agree with Bates and Mallard's room temperature value (409×10^{-6}) and have investigated the change of susceptibility with phase changes at 640 and 760° C (*43*).

Four Unpaired Electrons

The earliest recorded measurements on Pu(IV) were made in aqueous solution by Howland and Calvin (*10*). They used their result as part of the argument that the susceptibilities of the ions in solution could be best interpreted on the basis of unpaired electrons in the *5f* shell. Elliott and Lewis have reported susceptibilities of PuF_4, $Rb_4Pu(SO_4)_4 \cdot 2H_2O$, $Pu(SO_4)_2 \cdot 4H_2O$ and $Pu(C_2O_4)_2 \cdot 6H_2O$ over the temperature range 76–300° K (*44*). They found that the susceptibility-temperature behavior varies widely from compound to compound and that the susceptibilities are considerably lower than the theoretical value obtained by Hund's method for a $5f^4$ electron configuration.

More recently, the author has investigated the behavior of the susceptibility of PuF_4 and PuO_2 on dilution with the isomorphous diamagnetic thorium compounds (*45*). With increasing dilution, the susceptibility of the Pu(IV) ion in the fluoride increases, and when extrapolated to infinite dilution it agrees with the theoretical value for a $5f^4$ electron configuration with the electrons in *L–S* coupling. Thus, the extrapolated experimental room temperature susceptibility is $3{,}020 \times 10^{-6}$, theoretical for $5f^4$ is $3{,}010 \times 10^{-6}$, and the spin-only value associated with $6d^4$ is $10{,}500 \times 10^{-6}$. The susceptibility-temperature behavior of $KPuF_5$ is very similar to that of PuF_4, but that of Cs_2PuCl_6 is much more complicated (*46*). Zachariasen has shown, however, that the quadrivalent ion does not exist in Cs_2PuCl_6, but rather the $PuCl_6^{2-}$ ion (*47*).

Plutonium dioxide has a susceptibility much below theoretical and there is no marked increase until there is less than 10% of plutonium in the solid solution. Then the rise is very steep and the susceptibility extrapolated to infinite dilution appears to be the same as in the fluoride. The possibility of some of the electrons being in *6d* levels cannot be entirely ruled out since the dilution behavior is suggestive of a strong cooperative phenomenon between neighboring ions in the lattice. However, most of the evidence suggests that when the ions contain four unpaired electrons, the *5f* shell is the ground state.

Five Unpaired Electrons

Measurements by Howland and Calvin (*10*) on the susceptibility at room temperature of the Pu(III) ion in solution and by Elliott and Lewis (*44*) on PuF_3 and $Pu_2(C_2O_4)_3 \cdot 9H_2O$ from 76–300° K were not easily interpreted. The values at room temperature were considerably lower than that required by theory for a $5f^5$ electron configuration. Dawson, Mandleberg, and Davies extended the measurements on PuF_3 and $PuCl_3$ up to about 600° K and found a minimum in the susceptibility-temperature curve similar to that of Sm(III) (*48*).

It was mentioned previously that Hund's predictions of the magnetic moments of ions of the lanthanide elements agree well with experiment except for samarium and europium. Van Vleck has shown (*loc. cit.*) that the discrepancy is due to the assumption, inherent in Hund's method, that the spectroscopic multiplet intervals are large compared to kT. If the multiplet intervals in these two ions are assumed to be comparable in energy spacing to kT, a much better agreement with experiment is found. The population of any one energy state will then be a function of the Boltzmann temperature factor. Allowing for this, the expression for the theoretical susceptibility becomes

$$\chi = N \sum_{J=L-S}^{L+S} [g_J^2 \cdot \beta^2 J(J+1)\ 3kT + \alpha_J] \times \frac{(2J+1)e^{-W_J\beta/kT}}{\sum (2J+1)e^{-W_J\beta/kT}}$$

where α_J is a temperature-independent contribution to the susceptibility which may be calculated from the predicted multiplets. In the other lanthanides, α_J is quite small, but in Sm(III) and Eu(III) it makes a large contribution to the susceptibilities. An interesting feature of this calculation is that the susceptibility of Sm(III) should have a minimum at about 440° K.

The experimental susceptibilities of $PuCl_3$ and PuF_3 show minima between 500 and 550° K, and the shape of the susceptibility-temperature curve is similar to that of Sm(III). Calculation by means of Van Vleck's formula shows that the theoretical susceptibility of an ion with a $5f^5$ electron configuration is higher than the experimental one for these compounds but that the choice of 58 as the screening constant used in the calculations gives a minimum in the same temperature region. Qualitatively, the results seem

TABLE 5—Summary of Magnetic Data on the Heaviest Element Ions

Number of unpaired electrons *6d* *5f*	0	1	2	(3) (3)	4	5	6	7
Th	Th^{4+}	Th^{3+}	Th^{2+}					
Pa								
U	UO_2^{2+}		U^{4+}	U^{3+} U(metal)				
Np		(?)NpO_2^{++}	NpO_2^+					
Pu			PuO_2^{++}		Pu^{4+}	Pu^{3+}		
Am							Am^{4+}	
Cm								Cm^{3+}

TABLE 6—Electron Configurations

Element	*At. no.*	*5f*	*5f-6d*	*6s*	*6p*	*6d*	*7s*
Fr	87			2	6		1
Ra	88			2	6		2
Ac	89			2	6	1	2
Th	90			2	6	**2**	2
Pa	91			2	6	3	2
U	92			2	6	**4**	2
Np	93		5	2	6		2
Pu	94	**5**		2	6	1	2
Am	95	**6**		2	6	1	2
Cm	96	**7**		2	6	1	2
Bk	97	8		2	6	1	2
Cf	98	9		2	6	1	2

to be good evidence that Sm(III) and Pu(III) have a similar electron configuration, f^5, but it remains to check the screening constant by other means.

Six, Seven Unpaired Electrons

Crane, Wallmann and Cunningham have reported measurements on about 1 mg of AmF_3 and consider that their results are consistent with a $5f^6$ electron configuration for the Am(III) ion (*49*). However, the susceptibility is considerably lower than theoretical. Extension of the measurements to dilute solid solutions and very low temperatures would be desirable before making a useful comparison with Eu(III) and a definite electron assignment.

On the other hand, measurements by Crane on CmF_3 in dilute solid solution in LaF_3 show that the molar susceptibility at room temperature ($26{,}500 \times 10^{-6}$) is very high and comparable with that of GdF_3 ($24{,}600 \times 10^{-6}$) (*50*). The theoretical susceptibility of Gd(III) is very much higher than all the preceding lanthanide ions. The ion is in an S state so that there should be no uncertainty arising from orbital quenching. Consequently, if the electron configuration of Cm(III) is the same, closer similarity of the susceptibility to Gd(III) might be expected than was the case with the corresponding heaviest element and lanthanide ions with less than seven unpaired electrons. The closeness of the experimental susceptibilities indicates that both ions do have the same configuration and that that of Cm(III) is $5f^7$.

Correlation of Data

Haissinsky has pointed out that from a chemical standpoint the differences between the cis- and trans-uranium elements are too well marked for their inclusion in one and the same series (*51*). There are numerous instances in which the chemical properties of thorium, protactinium, and uranium have been shown to be much more closely related to the elements of Groups IV, V and VI, respectively, rather than to each other or to the corresponding lanthanides. Zachariasen claims that the characteristic valency of the seventh period elements is four (*24*). As far as they are available, the magnetic properties of the quadrivalent ions are in agreement with Haissinsky's argument. Thus U(IV) has electrons in the 6*d* level whereas Pu(IV) has them in the 5*f* level.

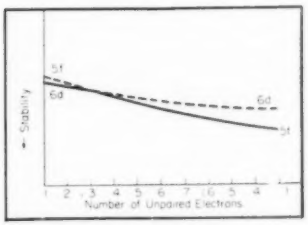

FIG. 2. Energy-level stability

Table 5 summarizes the magnetic data at present available and Table 6 gives the electron configurations of the elements beyond francium as deduced mainly from the magnetic data on the ions. It may be that these configurations will differ from the results of spectroscopic investigations on the free gaseous atoms, but since they are deduced from the properties of the ions they would seem to be a more reasonable basis for determining the way in which the heaviest elements should be written into the periodic table. The unpaired electrons on which the most definite evidence is available are printed in bolder type. Neptunium seems to occupy an intermediate position. It is probable that the 6*d* and the 5*f* energy levels are very close in the Np(IV) ion. A more extensive study of neptunium compounds may reveal that either level may be stabilized according to the particular crystal environment.

In his article, Seaborg (*loc. cit.*) has given a rough qualitative diagram of the binding energy of the most easily removable 5*f* and 6*d* electron for each of the heaviest elements. A similar type of diagram, based on the susceptibility results, is given in Fig. 2 in which the stability of the two levels is plotted against the number of unpaired electrons. It should be stressed that the property which determines the lowest level seems to be the number of unpaired electrons rather than the atomic number, in agreement with the Sommerfeld-Kossel rule.

It is obvious that there are still a number of gaps remaining to be filled by further susceptibility measurements, both by the methods discussed here and also by paramagnetic resonance absorption at low temperatures.

* * *

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BIBLIOGRAPHY

1. N. Bohr, *Nature* **112,** 30 (1923)
2. J. C. McLennan, A. B. McLay, H. G. Smith, *Proc. Roy. Soc. (London)* **A112,** 76 (1926)
3. Y. Suguria, H. Urey, *Kgl. Danske Videnskab. Selskab Mat.-fys. Medd.* **7,** No. 13, 3 (1926)
4. G. Seaborg, J. Katz, W. Manning, "The Transuranium Elements," National Nuclear Energy Series V-14B ½ (McGraw-Hill Book Co., Inc., New York, 1949)
5. G. Seaborg, NUCLEONICS **5,** No. 5, 16 (1949)
6. S. G. Thompson, A. Ghiorso, G. T. Seaborg, *Phys. Rev.* **77,** 838 (1950); S. G. Thompson, K. Street, A. Ghiorso, G. T. Seaborg, *Phys. Rev.* **78,** 298 (1950)
7. F. Hund, *Z. Physik* **33,** 855 (1925)
8. J. H. Van Vleck, "The Theory of Electric and Magnetic Susceptibilities," ch. 9 (Oxford University Press, New York, 1932)
9. M. Calvin, *et al.* p. 632 in ref 4.
10. J. J. Howland, M. Calvin, AECD-2440 (1948)
11. E. D. Eastman, L. Brewer, L. A. Bromley, P. W. Gilles, N. L. Lofgren, *J. Am. Chem. Soc.* **72,** 4019 (1950)
12. J. K. Dawson, R. D'Eye, unpublished data
13. E. D. Eastman, *et al. J. Am. Chem. Soc.* **72,** 2248 (1950)
14. W. Klemm, E. Hoschek, *Z. anorg. Chem.* **226,** 359 (1936)
15. W. Klemm, H. Steinberg, *Z. anorg. Chem.* **227,** 193 (1936)
16. W. Sucksmith, *Phil. Mag.* **14,** 1115 (1935)
17. W. J. de Haas, C. J. Gorter, *Proc. Acad. Sci. Amsterdam* **33,** 949 (1930)
18. C. A. Hutchinson, Jr., Technical Rep. No. 1, contract N6 ori-20 (Office of Naval Research, Washington, D. C., 1951)
19. T. deBruin, P. Klinkenberg, P. Schuurmans, *Z. Physik* **122,** 23 (1944); **118,** 58 (1941)
20. R. Lawrence, *J. Am. Chem. Soc.* **56,** 776 (1934)
21. J. K. Dawson, M. W. Lister, *J. Chem. Soc.*, 2181 (1950)
22. W. Trzebiatowski, P. W. Selwood, *J. Am. Chem. Soc.* **72,** 4504 (1950)
23. J. K. Dawson, *J. Chem. Soc.* 2889 (1951); 1185 (1952)
24. W. Zachariasen, NNES V-14A, ch. 18
25. N. Elliott, *Phys. Rev.* **76,** 431 (1949)
26. J. K. Dawson, *J. Chem. Soc.*, 429 (1951)
27. L. Sacconi, *R. C. Accad. Lincei*, 6 Sem 1(5), 639 (1949)
28. L. Pauling, *J. Am. Chem. Soc.* **53,** 1367 (1931)
29. G. E. Kimball, *J. Chem. Phys.* **8,** 188 (1940)
30. H. Haraldsen, R. Bakken, *Naturwissenschaften* **28,** 127 (1940)
31. R. Stoenner, N. Elliott, *J. Chem. Phys.* **19,** 950 (1951)
32. C. A. Hutchinson, Jr., N. Elliott, *J. Chem. Phys.* **16,** 920 (1948)
33. C. A. Hutchinson, Jr., N. Elliott, AECD-1896 (1948)
34. J. K. Dawson, AERE C/R-876 (U. K. Atomic Energy Research Establishment, 1952)
35. J. Dawson, A. Truswell, unpublished data
36. S. W. Rabideau, AECU-1130 (1951)
37. H. Bommer, *Z. anorg. Chem.* **247,** 249 (1941)
38. A. E. Long, W. M. Jones, J. Gordon, *J. Chem. Phys.*, in the press
39. G. N. Walton, G. Hutton, J. Dalziel, private communication
40. W. Klemm, E. Krose, *Z. anorg. Chem.* **253,** 226 (1947)
41. E. F. Westrum, Jr., J. B. Hatcher, D. W. Osborne, American Chemical Society meeting, Chicago, September, 1950
42. L. F. Bates, J. R. Mallard, *Proc. Phys. Soc. (London)* **863,** 520 (1950)
43. C. J. Kriessman, T. R. McGuire, *Phys. Rev.* **86,** 71 (1952)
44. N. Elliott, W. B. Lewis, Paper 90, Symposium on "The Chemistry of the Actinide Elements," American Chemical Society meeting, Chicago, September, 1950
45. J. K. Dawson, *J. Chem. Soc.*, 1882 (1952)
46. J. K. Dawson, unpublished
47. W. Zachariasen, *Acta Crystall.* **1,** 268 (1948)
48. J. K. Dawson, C. J. Mandleberg, D. Davies, *J. Chem. Soc.*, 2047 (1951)
49. W. W. T. Crane, J. C. Wallmann, B. B. Cunningham, UCRL-846 (1950)
50. W. W. T. Crane, UCRL-1220 (1951)
51. M. Haissinsky, *J. Chem. Soc.*, 8241 (1949)

Medium-Energy Nuclear Physics

The latest discussions on nuclear structure focus attention on new results as well as old puzzles. Here is a summary of the trends in some current thinking on the subject

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SOME OF THE new information developed in the search for a more accurate picture of the atomic nucleus is beginning to fit together rather well. Nevertheless, no general framework that gives promise of unifying all the results is yet apparent. For heavy nuclei, the data are all fitting very well into the shell model of Mayer and Haxel, Jensen, and Suess, which postulates strong spin-orbit forces, or *jj*-coupling; for light nuclei, this is not the case. For the very lightest, a model in which Russell-Saunders, or *LS*-coupling, predominates is more successful.

These points were brought out at a conference on medium-energy nuclear physics held on June 5, 6, and 7 in Pittsburgh, Pa. The University of Pittsburgh, with David Halliday, chairman of the department of physics serving as head of the committee in charge, organized the conference and played host to it. For all attending, the meeting, combined with well-planned leisure time for additional discussions, proved a most rewarding affair.

Heavy Nuclei

Among the contributions which emphasized the validity of the Mayer-Jensen shell model for heavy nuclei was that of *G. Scharff-Goldhaber* (Brookhaven National Laboratory). She reported on the study of the character and position of the low-lying states of even-even nuclei. In 43 cases where data exist, the spin and parity of the first excited level are found to be, with only two exceptions, 2, even (+), respectively. The second excited state is found to be most frequently 2+ or 4+. These observations suggest the rule that the spin of the nth excited state is $\leq 2n$. Such a result has recently been predicted theoretically by Flowers and by Kurath from the *jj*-coupling model for an even number of nucleons.

Scharff-Goldhaber finds that the energy of the first excited state, when plotted against the number of neutrons or protons in the nucleus, reaches maxima at the magic numbers. Except for the magic-number cases, however, it turns out, rather surprisingly, that the position of this first level is less affected by the addition of two protons than by the addition of two neutrons.

The writer reported systematizations of β-decay energies and neutron and proton binding energies. The β-systematics clearly exhibits discontinuities at the magic numbers, 50, 82, and 126, but not so far at 20 or 28.

Computations from experimental data of the binding energy of the "last" neutron or proton in the regions of Sn and Pb revealed the actual magnitude of some of the discontinuities and gave quantitative results for these binding energies as functions of neutron or proton number. As predicted by the *jj* shell model, a sudden decrease in the difference between the binding energy of an even and an odd proton was noted after the magic proton number 50. Just after the doubly magic nucleus Pb^{208} (with 82 protons and 126 neutrons), the binding energies can be represented in a very simple way by assuming the existence of potential wells for neutrons and protons, bonds between like particles in pairs only, and quickly saturated bonds between unlike particles.

Angular Correlation

S. Ridgway (Princeton University) discussed his experimental work on β-γ angular correlation in Sb^{124}, Rb^{86}, and As^{76}. The fact that correlation is observed in the case of As^{76}, in spite of the apparently allowed shape of the Fermi plot of the β-spectrum, is understandable in terms of nucleon spin changes predicted by the *jj* shell model. The results for Sb^{124} and Rb^{86} are also interpretable in the light of the model and fit in with the rule discussed by Scharff-Goldhaber.

The measurement of the angular correlation of two nuclear radiations which are in cascade provides information on the spin of the initial, intermediate, and final nuclei involved. The results which have been reported by a number of authors are important for checking predictions of nuclear models. *M. E. Rose* (Oak Ridge National Laboratory) reviewed the effect of external fields on angular correlation measurements and pointed out that the magnetic interaction of its own electrons with the decaying nucleus can sometimes remove the sought-for anisotropy. Such interactions can be nullified by the application of an external field or prevented by the form of the solid sample investigated.

Magnetic Moments

A. de Shalit (Princeton University) pointed out that deviations of magnetic moments from the Schmidt limits are greater for odd Z nuclei than for odd N nuclei if $Z = N$. His calculations showed that this rule can be understood semi-quantitatively on the assumption that the nuclear magnetic

moment is due entirely to a group of odd nucleons in the nucleus, each one of which has the same angular momentum. Such an assumption predicts directly larger deviations for a group of n odd protons than for a group of n odd neutrons but gives no indication of the sign of the deviation. The fact that almost all magnetic moments lie inside the two Schmidt lines may be explained, de Shalit suggested, by assuming that the ground state of an odd A nucleus is a mixture of a state in which the core has zero spin and even parity with a state in which the core has spin 2 and again even parity. These latter states of the core are the first excited states of even-even nuclei discussed by Scharff-Goldhaber.

Butler Theory

S. T. Butler (Cornell University) discussed his theory of the angular distribution of neutrons or protons from (d,n) or (d,p) reactions and reported that recent work shows only small changes in his results when Coulomb corrections are taken into account. The Butler theory assumes that the incident deuteron is stripped of either neutron or proton as it passes the target nucleus. If the target nucleus accepts a particle of angular momentum l_n from the passing deuteron, the partner particle proceeds in a direction determined by l_n. A measurement of its angular distribution identifies l_n and thus gives information about the spin and parity of the product nucleus. Experimental distributions have been found so far to agree quite well with the theoretical ones.

Results from application of the Butler theory have particular importance for β-ray problems. *H. W. Fulbright* (University of Rochester) reported that the accepted particle in both the $C^{13}(d,p)$ and $C^{13}(d,n)$ reactions has $l_n = 1$. The parities of the ground states of C^{14} and N^{14} must thus be the same. Since the spin difference between them is 1, the β-decay of C^{14} is certainly allowed and the puzzle of its long lifetime is definitely accentuated. Similarly (d,p) and (d,n) reactions on Be^9 establish the fact that there is no parity difference between Be^{10} and B^{10}. The β-transition between these two nuclei is then established as belonging to the $\Delta I = 2$, no type.

The Butler theory was also made use of by *H. E. Gove* (Massachusetts Institute of Technology) in a study of (d,p) reactions in both light and heavy elements. It played an important part, too, in the spin and parity assignments of the B^{10} levels discussed by *H. T. Richards* (University of Wisconsin). The level scheme of this nucleus has been carefully worked out through a number of experiments by the Wisconsin group and others and is now one of the best known. Both ordinary and isotopic spins can now be assigned to most of the levels below 5 Mev.

Isotopic Spin Conservation

The usefulness of the isotopic spin concept was stressed by *R. F. Christy* (California Institute of Technology) as well as by Richards. According to this concept, levels in different isobars, which apart from Coulomb differences, have the same energy values, can be assigned a common isotopic spin number, T. Such levels have been identified in a number of cases. They have, of course, a common value of the ordinary spin. Their existence implies charge-independent nuclear forces.

Evidence is accumulating that isotopic spin is conserved in nuclear reactions and that the isotopic spin concept can therefore be used in predicting the possibility of certain nuclear reactions. Richards pointed out that the 1.73-Mev level in B^{10} ($T = 1$) is not excited by the inelastic scattering of deuterons just as one would expect if a conservation rule held. (The initial particles, H^2 and B^{10} both have $T = 0$. The outgoing deuteron also has $T = 0$, so if T is to be conserved, the final state of B^{10} must also have $T = 0$ and the 1.73-Mev level with $T = 1$ is not a possible final state.) Christy pointed out another striking example of a reaction apparently forbidden because of isotopic spin conservation, namely $O^{16}(d,\alpha)$(2.3-Mev level of N^{14}). This level again has $T = 1$ while all the other particles involved have $T = 0$.

Light Nuclei

New results which should lead to a clearer picture of nuclear structure in the region $Z = 10$–20 were presented by *W. W. Buechner* (Massachusetts Institute of Technology). The MIT group, with the use of a magnetic spectrometer, is able to make very accurate measurements of the energies of emitted particle groups in (d,p), (d,α), (p,α), etc., reactions. In this way they find level values in the product nucleus as well as mass differences between ground states of the target and product nuclei.

Energy levels in the region $Z = 10$–30 are being studied by a University of Pittsburgh group by means of magnetic analysis of inelastic proton scattering. Their carefully shielded, underground scattering chamber was described by *R. S. Bender*.

Attempts to understand theoretically the structure of light nuclei are turning out to be more successful in terms of an LS-coupling model rather than the jj one which is working so well for heavier nuclei. If further investigation establishes the fact that different models are actually needed for light and heavy nuclei, the question of where and why a change from LS to jj-coupling takes place will be an important one.

Christy reported greater success with LS than with jj-coupling in predicting the angular distribution of γ-rays from such reactions as $p + t \rightarrow He^4 + \gamma$. *E. P. Wigner* (Princeton University) pointed out that calculated values of quadrupole moments of light nuclei are in much better agreement with experiment if LS rather than jj-coupling is used. He also noted that Trigg and Feenberg get good results for the ft values of mirror nuclei with LS-coupling and a mixture of Fermi and G-T coupling constants.

D. R. Inglis (Argonne National Laboratory), however, suggested that a change-over is taking place at B^{10}. He investigated the levels for p-shell particles and found the best fit for B^{10} for an intermediate-type coupling.

Perhaps the most hopeful note of the meeting was sounded by Wigner who discussed some recent calculations by Feingold on the spin-orbit level splitting resulting from the addition of small amounts of tensor forces in an LS-coupling model in light nuclei. Earlier results of Dancoff had shown the calculated effect to be much smaller than the observed one in He^5, but Wigner noted that when polarization of the nuclear core is taken into account, the calculated splittings are in fair agreement with the experimentally observed values in three cases. These new results lead to the hope that a tensor force may explain the strong spin-orbit coupling that is basic for the jj-shell model for heavy nuclei.

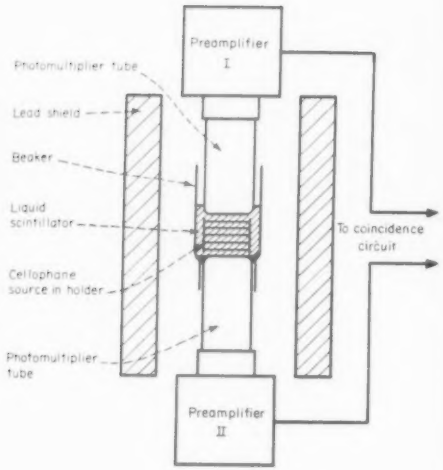

FIG. 1. Schematic of liquid-scintillation beta counting arrangement set up for multiple counting

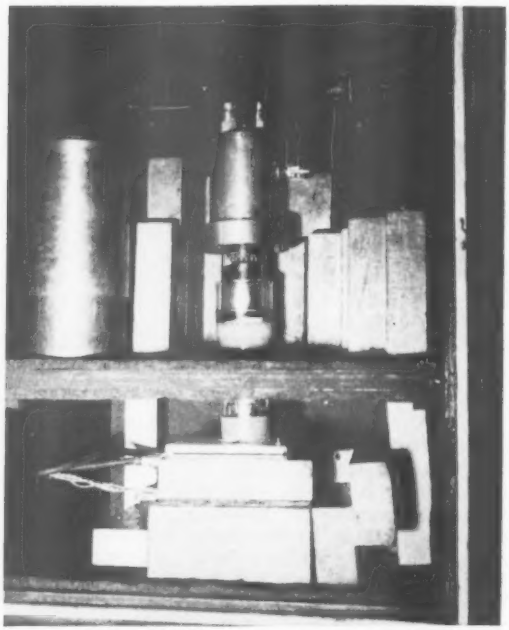

FIG. 2. Arrangement for volume counting (with shielding removed). Upper tube is immersed in a liquid-phosphor paste

Liquid Scintillation Beta Counter for Radioactive Solids

DETERMINING very low specific beta-ray activities is a difficult problem at best, and particularly so where low-energy particles are concerned. In attempting a modification of one of the three methods of beta counting in current use, our laboratory weighed their specific uses against their disadvantages as follows:

Gas counting. Geiger tubes, windowless flow counters, and ionization chambers are the instruments involved in gas counting. The disadvantage in this method is that it does not allow for the use of large amounts of counting substance and that only active elements forming gaseous compounds can be counted.

Liquid-phosphor counting. Dissolving a radioactive substance into the liquid phosphor of a scintillation counter is a method that is very efficient,* but it, too, has the drawback that large amounts of solute cannot be used. They would produce a quenching of the scintillations. [In the case of this method, we suggest that since all liquid phosphors have as their base a substance rich in carbon (e.g., toluene, xylene, benzene, etc.) it may be feasible to incorporate carbon-14 chemically into the phosphor base. This would involve complicated chemical synthetic work in preparing toluene, etc., from the elements, but the method might be useful in geological and archeological dating and carbon bioassay work if very high sensitivity is required.]

Solid-sample counting. In general, preference will always be given to this method of counting. However, with thin-window Geiger tubes used in this

* M. S. Raben, N. Bloembergen, *Science* **111**, 363 (1951)

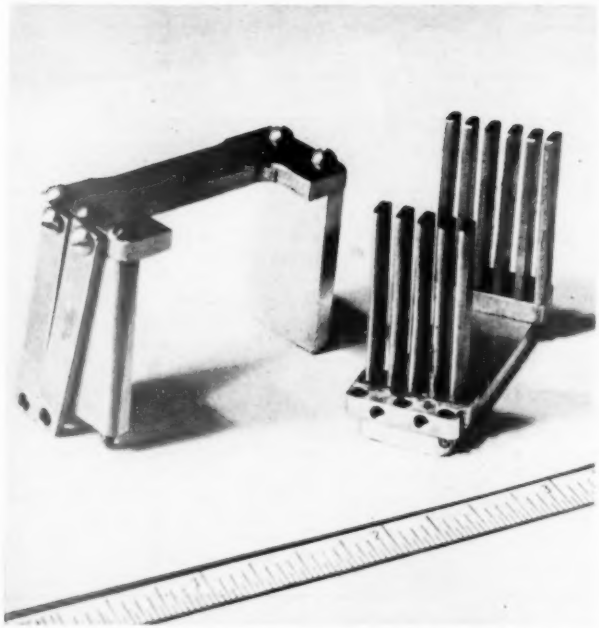

FIG. 3. Metal holder for stacking cellophane sheets on which radioactive substance is evaporated for multiple-sample counting

FIG 4. Beaker, into which upper tube dips, is cemented on lower tube

Less than 10^{-3} microcurie has been measured in the counter which permits use of larger-than-usual samples. A wide variety of solid materials can be accommodated for both multiple-sample and volume counting

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work, the amount of counting substance is also necessarily small; with screen-wall counters, the amount of sample can be larger but here counting depends on the surface area rather than on the mass.

In connection with solid-sample counting, our laboratory has had under development for some time the liquid scintillation counting method described here.

It is a counter that can take two different forms, depending on the amount of radioactive sample available. It can operate either as a *multiple-sample counter* for small amounts or as a *volume counter* for large amounts.

In both instances the substance has to be insoluble in the phosphor and of sufficient transparency; that is, the method can be applied to all inorganic salts, amino acids, proteins, and divers biological material. With conventional photomultiplier tubes the method is at present limited to non-colored substances. The second method can also be used for assaying the activity of solutes, vapors, and gases in the adsorbed state, with the help of a transparent adsorbent.

Figures 1, 2, and 3 show the two counting arrangements possible.

Two photomultiplier tubes (RCA 5819) are used. A beaker to hold the radioactive sample is cemented to the lower tube in the manner shown in Fig. 4; the upper tube extends into the liquid phosphor.

The shielding (see Fig. 5) consists of an iron cylinder surrounding the tubes, a lead castle, and iron and lead on the top of a lighttight cabinet containing the counter. Coincidence counting is applied. The phosphor used is toluene and para-terphenyl

(4 grams of terphenyl in 1 liter of toluene).

Multiple-Sample Counter

A small amount of radioactive substance is evaporated from a solution on sheets of cellophane to form a thin layer (area about 4 cm^2) on one or both sides of the cellophane. Several such activated cellophane sheets can be stacked together with the help of a special holder, such as the one shown in Fig. 3.

In one arrangement, a strip of cellophane 12 inches long and 1 inch wide, is folded and stretched over in such a way as to give 10 parallel layers. The cellophane holder is placed in the beaker between the multiplier tubes with the sheets parallel to the photocathode, and the beaker filled with the liquid phosphor. Since both cathodes are in direct contact with the counting fluid, good optical coupling is assured.

The light absorption in cellophane is very small, and as the refractive indexes of the cellophane and the liquid phosphor are nearly the same, light losses through multiple reflection are also small. Difficulties exist in spreading the solutions evenly over the cellophane surface. Crinkling of the cellophane can be reduced by keeping it under stress. The thin layers of active material used make corrections for sample thickness unnecessary.

The distance between the cellophane sheets is 1 mm, so that a stack of 10 sheets can be placed between the photocathodes 12 to 15 mm apart. With 20 effective layers between the counters, 20 times more counts are obtained than with a thin-window Geiger counter using only one such layer, not considering the much higher efficiency of the liquid scintillation counter and the good geometry of the arrangement. The background, partly because of the mass of the metal holder, is of the order 2 counts per second. This permits an accurate count of 4 cps above background, or 240 cpm, corresponding to an activity of about 10^{-4} μc. If 0.1 gram of active material is spread over all the layers, the specific activity of the radioactive substance is 10^{-3} μc gm.

Measurements were made with C^{14} in form of sodium carbonate, and with S^{35} in form of sodium sulphate and sulphuric acid. These measurements indicate that total activities of less than 10^{-3} μc can be observed with a sufficient degree of accuracy in short counting times. The counting efficiency depends on the technique of sample preparation, but it can be maintained at greater than 10%. This means that an observed activity of 10^{-4} μc is due to an actual activity of not more than 10^{-3} μc.

It is possible to reduce the number of cellophane sheets and still maintain the total area by using large-surface multiplier tubes, such as the RCA H-5037.*

A somewhat similar arrangement could be obtained with thin plates of plastic phosphor. The radioactive substance can be evaporated directly on the surfaces of the plates, or activated cellophane sheets can be sandwiched between the plates. A solid block of several such plates could be placed between the photocathodes, immersed in a suitable liquid to guarantee optical contact.

Measurements with Volume Counter (Amount of Liquid Phosphor = 25 cm^3)

Substance (in liquid phosphor)	*Effective mass (grams)*	*Counts per sec*	*Counts per sec with Co^{60} source*
Liquid phosphor	25	1.9	67
KCl	40	280	340
KCl in pure toluene	40	1	1
KNO_3	50	140	182
NaCl	50	1	57
KCl + NaCl (20 + 25 gm)	45	137	192
NH_4Cl	25	1	33
NH_4Cl after neutron bombardment, 50 hr	25	5	34
NH_4Cl after neutron bombardment, 100 hr	25	11	53
Silica gel, wetted with distilled water (8 gm)	38	1	30
Silica gel wetted with active H_2CO_4 (9 gm) (unknown strength)	39	10	38
Urea	30	1	37
Urea with added active urea 0.4 mg	30	158	194
Urea after neutron bombardment, 50 hr	25	1.6	39
Urea after neutron bombardment, 100 hr	25	3.5	50
Dextrose	40	1	45
Starch	40	0.8	22

Volume Counter

In many instances the solid radioactive substance can be mixed into the liquid phosphor to give a paste (e.g., 40 gm of a salt in 25 cm^3 of fluid). When the paste is placed in the beaker attached to the lower tube, with the upper tube dipped into the paste as seen in the photograph in Fig. 1, counts are obtained in numbers that depend on the light transmission of the paste, other things being equal. The distance between the photocathodes can be varied from a few millimeters to two centimeters.

A measure of the transparency of the paste to the light from the scintillations can be made with the help of a cobalt-60 source (about 0.02 mc) producing additional light flashes in the sample.

To observe whether scintillations from low-energy beta particles (such as those from S^{35} or C^{14}) would be counted, a cellophane sheet activated with S^{35} was placed in the paste in the middle between the tubes. The transparency of commercially available noncolored crystallized salts (C.P.) is in many instances high enough to ensure a high efficiency of counting.

The table on this page gives some of the results of measurements made with this counter arranged for volume counting.

* M. H. Greenblatt, M. W. Green, P. W. Davison, G. A. Morton, NUCLEONICS **10**, No. 8, 44 (1952)

The natural activity of potassium, due to the presence of K^{40}, is easily and accurately measured in a matter of minutes. It is interesting to compare this result with one obtained* with a thin-walled Geiger counter dipping into a potassium salt solution of 200 ml, where 400 cpm were counted above the background of 200 cpm. In the volume counter, the background is only about 60 cpm and the total count of the order of 17,000 cpm. This means that the activity even in a dilution of 10^{-3} could be observed. Since about half of the mass of potassium chloride is potassium and 1 gram of potassium gives about 30 dps, a 100% counting efficiency would lead to 600 cps/50 gm; we find 280. This result suggests an efficiency of the volume counter for KCl of about 50%. A few of the counts come from the gamma radiation of potassium. The loss must be due mainly to the geometry of the arrangement, some light absorption, etc. The high efficiency is due to the high-energy beta particles and to the good transparency of the potassium chloride-phosphor paste; the latter is indicated by the difference of 60 cps between the normal count and the count with the cobalt-60 source, which is 340 cps.

Potassium nitrate is less light-transparent, the difference being only 42 cps. With KNO_3 there are about 20 grams of potassium and theoretically 600 cps. Our result is 140 cps; thus the efficiency here is only 25%.

Sodium chloride shows no natural activity; the transparency is somewhat less than that of KCl. A mixture of sodium chloride and potassium chloride crystals gives a proportional reduction in counts.

Ammonium chloride paste is also of sufficient transparency, and C^{14} induced in it by neutron bombardment from a 50-mg radium-beryllium-paraffin source gives, after a short time, an easily measurable activity.

Urea also seems to be a good material for the counting of active carbon. In one sample, C^{14} was induced by neutron bombardment. In a second sample, about 0.4 mg of activated urea (about 30,000 cpm/mg or, assuming a counting efficiency of 1%, approximately 1 μc/mg) were dissolved in a solution of 30 grams of ordinary urea, and the activity of the recrystallized sample measured. In the 30 grams of activated urea used, the number of disintegrations is of the order of 20,000 dps, which is about 100 times more than our count of 158 cps. This means that the volume counter operates for low-energy beta particles with an absolute efficiency of about 1%.

The advantage of the volume counter, however, lies in the possibility of measuring low specific activities. Dextrose and starch have also a sufficient light transparency, though used in the form of fine powders. Their normal activity is the expected background.

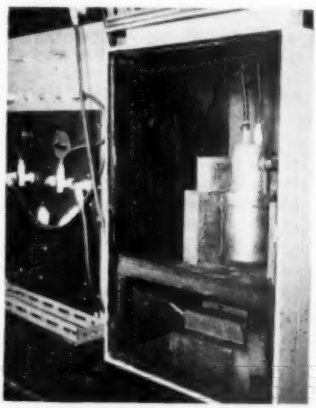

FIG. 5. Counting arrangement ready for operation with shields in place

To increase the light transparency of fine powder samples, it might be possible to mix such powders, particularly nontransparent active material like soils, dust, etc., with a coarse nonactive transparent material (e.g., rocksalt, glass powder, quartz powder) that would act as a light-guide. To count low-energy beta particles (and also alpha particles), the radioactive material must be in the form of small crystals so that the emission can leave the crystal. On the other hand, with too great packing of finely ground powders, too small an amount of scintillating fluid is present between the solid particles, in which case, also, a more coarse nonactive powder has to be mixed into the paste.

The paste volume-counting method could be applied also to radioactive solutes, vapors, and gases, that can be adsorbed on materials like silica gel, chabasit, zeolithes, gelatine, etc. The adsorbens is then placed in fine dispersion in the scintillating liquid. We are exploring the applicability of this method to determine the activity of water and air pollution and to measure radioactive emanations from earth, wells, and the respiratory gases.

Biological material (muscle, bone, plant material, molds, bacterial cultures, etc.), dried and powdered or shredded, could be dispersed (after fat-like substances have been extracted) in the liquid phosphor directly, or the ash of such material could be used. In many instances this would remove the necessity of complicated chemical recovery of the radioactive substance. Very low concentrations of radioactive tracers could be assayed immediately from large amounts of the tissue or other biological substances (e.g., red cells).

We have so far investigated a few materials of biological origin. Among them were a technical gelatine, a proteose, casein, and agar. Since these substances are more or less yellow, they absorb too much of the blue light to which the photomultiplier responds. Such substances have to be investigated in sufficient dispersion in other solid transparent materials. A liquid phosphor giving scintillations of more yellow colored light, in combination with yellow-sensitive phototubes would be useful, for example, for the study of blood cells.

Large-area photomultiplier tubes could be used to advantage in this type of volume counter, since it would allow, for equal volume between the photocathodes, a reduction of the distance between the cathodes, which leads to an improved transparency of the paste and better utilization of nearly all of the scintillation flashes.

* * *

The authors wish to thank Dr. H. S. Zbarsky of the Biochemical Department for the radioactive substances supplied by him. Funds for the work were provided through a National Research Council (Canada) research grant (G264, March 22, 1951) to the senior author (O.B.). The junior author (F.T.) gratefully acknowledges a research fellowship grant for 1951/52 from the Canadian National Research Council. The photographs used are reproduced here through the courtesy of the Visual Education Service, University of British Columbia.

* R. Barnes, D. Salley, *Ind. Eng. Chem. Anal. Ed.* **15**, 4 (1943)

How An AEC Operations Office Does Business

By WILBUR E. KELLEY
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U. S. Atomic Energy Commission
New York, New York

What the Atomic Energy Commission looks for in the companies it selects for AEC work and the type of contracts it offers is outlined in this account of how its New York office operates

CONTRACT POLICIES of the AEC, while more or less standardized among the eight operations offices that administer its work, depend upon several interrelated factors. By examining typical procedures used by the Commission's New York Operations Office (NYOO), it is possible to see what some of these factors are.

Fixed-price (unit price or lump sum) contracts and open competitive bidding for services and materials are used whenever possible and wherever security considerations permit. Often, however, advertising for bids is impractical; such is the case either when the item required is not available on the open market (example: production in a specialized field), is not offered for sale on a bid basis (example: architect-engineer services), or cannot be readily specified (example: fundamental research).

Types of Contracts

Where a fixed-price contract is impractical, NYOO tries for a negotiated, fixed-price contract.

In larger production contracts, where there is continued procurement over a long period of time, NYOO uses a price-revision type of contract. This is essentially a fixed unit price contract for a definite short period—three or four months, for example—with provision for a new fixed unit price to be negotiated before each ensuing period. This type of arrangement retains management incentive for the contractor, but at the same time permits the Commission to obtain long-term benefits resulting from the contractor's incentive to reduce costs and thereby increase his profits.

NYOO also uses other types of unit price contracts with price revision, for example, contracts in which a provisional unit price is used initially with provision for upward or downward revision after a certain percentage, say, 25%, of the production has been completed, or contracts with a provisional unit price (or lump sum) subject to negotiation or downward revision at our request upon completion of the work.

Where the criteria for a fixed price contract (including the price revision type) cannot be met, some variation of the cost-plus-fixed-fee or a cost type contract is negotiated (example: research and development work). Lump-sum contracts are widely used for small basic research contracts with educational institutions, however, because in this case there is no profit factor and the institution provides some financial support of the work to be done from its own funds.

In development contracts for radiation-detection instruments, New York generally uses a time, or a time-and-material contract with a profit ceiling. The time rate includes a profit factor for a specified number of hours, and additional hours if required are at an adjusted rate which excludes profit.

Cost Plus

In other important contracts, such as major construction contracts, good judgment may call for a cost-plus-fixed-fee contract to permit control of the character of work and expense rather than to commit the Commission in advance to too expensive or cheap a job without prior knowledge of the quality needed.

The contract for operation of the AEC's new feed materials production center is of the cost-plus-fixed-fee type, a departure from our present method in feed-material contracts. This is the installation in Fernald, Ohio, for which Congress has appropriated $78,000,000, with supervision a responsibility of NYOO. We chose the cost-plus contract in this case because (*a*) the work is to be carried out in completely Government-owned facilities which are of new design and may require major changes during initial operation, and (*b*) the feed material for the plant will be of varying types and not easily predictable as to effect on production efficiencies and capacities.

No contractor under these circumstances could afford to quote a unit price without including large contingency items, which would destroy the advantages to the Government

of a unit price contract. In situations like Fernald, the cost-plus-fixed-fee contract seems to be the most practicable and the fairest to the Government and contractor. In this particular case, the contractor's fee is small in relation to his effort.

One may well ask how we can obtain competition at all in the negotiated unit price or cost-plus-fixed-fee contracts. We obtain competition through our procedures, although the competition is by no means as apparent as in advertised awards. Often the contractors eliminate themselves.

Selection of Contractor

Where formal advertising is not practicable, the Commission discharges its responsibility to obtain the best contractor for the job by making a careful survey of those interested firms which are technically competent in the field. In all instances, proposals are solicited from several contractors.

The procedure we used in selecting the construction contractor for the feed materials production center will illustrate this point. First, we established seven special qualifications that the prospective contractor should have:

1. A wealth of successful construction experience, particularly in chemical processing plants.
2. Ability to provide adequate key personnel.
3. Evidence of willingness to give preferential treatment to the project.
4. Strong management (labor relations, safety, accounting).
5. Ability to perform major portion of work with own employees.
6. Ability to procure and expedite materials.
7. Familiarity with site conditions.

We reviewed all construction firms which had asked to be considered for future work and others which had come to our attention, twenty firms in all. As a result of meetings with these firms, and a review of their ability to meet the seven special criteria, we determined that only five were qualified and interested. Three of the five were eliminated upon closer review because of such factors as unwillingness to assign key personnel, no recent large construction experience in the United States, or their relative lack of experience in constructing complicated chemical processing plants.

Of the remaining two firms, one was already heavily committed in the atomic-energy program. Since the other met all our criteria and the award of the contract to this firm would not require a dilution of effort on other atomic-energy work, it received the contract. The contractor selected had never done work for the AEC before.

Unit Price Work

In general, and except for the feed materials production center contract, mentioned previously, the processing of uranium feed materials is presently done through unit-price type contracts administered by NYOO. Under the unit price arrangement, the Government negotiates, generally quarterly, with the contractor to establish a forward price per unit of material produced to specifications.

Feed material from which uranium oxides are produced includes raw uranium ore, uranium concentrates and various uranium scraps recovered throughout the processing chain. In the case of raw ore and concentrates, many impurities are present that must be extracted; uranium scrap, on the other hand, may be quite pure or may contain only a few per cent uranium per unit bulk. The chemical processing of such dissimilar materials demands flexibility of operation so as to achieve high efficiency in recovery of the uranium.

The first unit prices agreed upon are estimates since there are no past actual costs available. At the end of the first pricing period, the contractor submits his projected costs with explanations for changes from experienced costs. After a Commission audit of the books kept on the work, the Government negotiators are in a better position to judge the validity of projected costs.

Prior to the renegotiation date, a meeting between contractor and AEC technical representatives is arranged to discuss costs and obtain preliminary agreement on increases or reductions.

Next a meeting of the five-man NYOO contract review board is held for a round-table discussion of the proposals. The board, whose members are chosen on the basis of experience from the technical, administrative, and fiscal staffs, advises the operations-office manager on contract matters.

The actual negotiations with the contractor now take place. All elements of the various items of cost are individually discussed, and a final projection agreed upon. Items of a capital nature are not used in the basic costs on which mark-ups are calculated; such capital items are directly reimbursed at cost without mark-up.

The mark-up includes both general and administrative costs, and profit and is a negotiated figure. After the total costs have been negotiated, they are divided by the scheduled production to arrive at a unit price for the delivered product. This price is tentatively agreed upon, subject to final approval of the contract review board and the manager.

Responsibility

In our contracts, both Government and contractor have clearly defined responsibilities. NYOO is responsible for technical coordination of the program, for setting up specifications for the product, for approving the production processes and analytical procedures, and for checking the contractor's chemical analyses. We approve the partial and final invoices for payment and supply the necessary feed materials. We set health, safety, security and accountability standards, issue shipping instructions, inspect plant and property records, and make fiscal audits.

The contractor is responsible for operating the plant and for meeting product specifications. His work includes hiring and training of personnel, the normal procurement of chemicals and equipment, maintenance, repair, and other related production operations. It is also his responsibility to maintain the health and security standards set by the AEC, and to arrange adequate control of, and accountability for, the uranium-bearing materials.

These, then, are some of the policies and procedures we employ in negotiating contracts. The permutations and combinations of these business arrangements sometimes seem limitless, but they provide the flexibility needed to get jobs done in this expanding and relatively uncharted field of atomic energy.

* * *

This article is based on a talk at Ann Arbor, Mich., before the University of Michigan Law School conference on atomic energy, June 27, 1952.

CROSS SECTIONS

Preparation of Radioactive Plastic Microspheres

By MANUEL TUBIS* and HOWARD I. JACOBS*

Subsequent to a study of myocardial shock produced by coronary occlusion (*1*), radioactive plastic microspheres were substituted for nonradioactive microspheres to facilitate determination of their location and quantitative distribution in the heart and other organs (*2*).

These "tagged" microspheres, which are available in a wide range of diameters, might be useful in other physiological studies such as the production of experimental specific organ damage in vascular organs, for instance, the kidney in hypertension studies. Our experience with their use in myocardial shock would indicate that they can be used to determine the location and extent of experimental microsphere emboli in vascular systems.

Their radioactivity permits radioautographs to be made of sections as thick as 1 cm. A quantitative estimation of the number of microspheres present, even after a period of several weeks, can be obtained with a scintillation counter (*3*).

Preparation of Microspheres

Microspheres used in this laboratory consisted of spheres of Dow Polymer X-772 P-9-5-1 polystyrene divinyl benzene of the required diameter. It was suggested (*4*) that I^{131} could be used for "tagging."

The operations are conducted behind a lead shield arranged in a flat metal tray lined with Kimpac paper, so as to prevent contamination and to reduce the radiation level below 6 mr/hr at the operator's working position. Rubber gloves must be worn to prevent absorption through the skin.

The technique devised and used in this laboratory in a typical preparation is as follows: Place 2 ml of methylene chloride (boiling point 40.5-42°) into a 60-ml separatory funnel having well-fitting stoppers and add 0.5 ml of 0.002*M* potassium iodide and 0.1 ml of 0.002*M* potassium iodate. Mix the solutions by swirling the funnel, leaving the top stopper loose so as to allow the release of the solvent vapors. Add to the funnel about 3 mc of carrier-free I^{131} contained in a small volume (several milliliters) and follow with 0.05 ml concentrated hydrochloric acid. Hereafter handling and contact should be at a minimum. Swirl to mix and allow to stand until the yellow aqueous solution shows precipitated iodine. Continue to swirl the funnel more vigorously and shake quickly to extract the iodine, frequently releasing the pressure by loosening the top stopper. Allow the methylene chloride to coalesce and draw it off into another similar funnel.

Repeat the addition of the chemicals except the I^{131}, and repeat the extraction. This should reduce the aqueous layer to low radioactivity. Draw off the second extraction into the second funnel.

Remove the aqueous layer and rinse the funnel with small portions of water which are then set aside for proper disposal.

Now wash the combined extractions with three successive 1-ml portions of water, combining these portions with those above for disposal.

Draw off the extractions into a 5-ml beaker containing about 100 mg anhydrous sodium sulfate. Stir, and if the sodium sulfate appears to be saturated, add successive 10-mg portions until the water appears to be removed.

Conduct the next operation in a well ventilated hood. Decant the "dried" solution into a 2-inch-diameter watch glass containing the desired quantity (100 to 600 mg) of the plastic microspheres. This watch glass is placed, in turn, in a 4-inch-diameter watch glass. Over the latter invert a funnel connected to the center inlet of a suction flask containing sufficient 0.01% potassium iodide solution to cover the inlet tube. Evaporate the solvent by aspiration through this solution to entrap any iodine vapor.

When evaporation is complete, transfer the microspheres to a fritted glass filter of coarse porosity and wash by slight suction with 500 ml of water containing 25 ml of 0.002*M* potassium iodide, checking the radioactivity of the last 5 ml. If the radioactivity is higher than about 0.5 μc, continue washing until this level is reached.

Dry the microspheres by aspiration until they are free flowing and then in a vacuum desiccator to constant weight. Determine the activity of about 0.5 mg and calculate the specific activity. Store in a stoppered container in a cool place until used.

Since the iodine is present in excess, it was found that 3 mc of I^{131} was sufficient to label from 100 to 600 mg of microspheres with about 2 μc/mg.

The iodine is fairly firmly bound, as shown by the fact that microspheres incubated with dog plasma lost only 0.05% of their count.

* * *

The authors wish to acknowledge the technical assistance of Panchita B. Thomas and to express their appreciation to the Dow Chemical Co. for the generous supply of the microspheres and helpful information. This work was supported in part by a grant from the Los Angeles County Heart Association to the Cardiovascular Laboratory. The article has been reviewed by the Veterans Administration and is published with the approval of the Chief Medical Director. The statements and conclusions of the authors are the result of their own study and do not necessarily reflect the opinion or policy of the Veterans Administration.

BIBLIOGRAPHY

1. C. M. Agress, *et al.*, *Am. J. Physiol.* **166**, 603 (1951)
2. C. M. Agress, *et al.* (to be published)
3. R. L. Libby (to be published)
4. W. C. Bauman, Assistant Director, Physical Research Laboratory, Dow Chemical Co., private communication

* Radioisotope and Cardiovascular Laboratories, General Medical Research Service, Wadsworth General Hospital, Veterans Administration Center, and the Department of Radiology, School of Medicine, University of California, Los Angeles, California. Mr. Jacobs is a Research Fellow.

FIG. 1. Continuous air monitor. Sampling hood is seen through open side

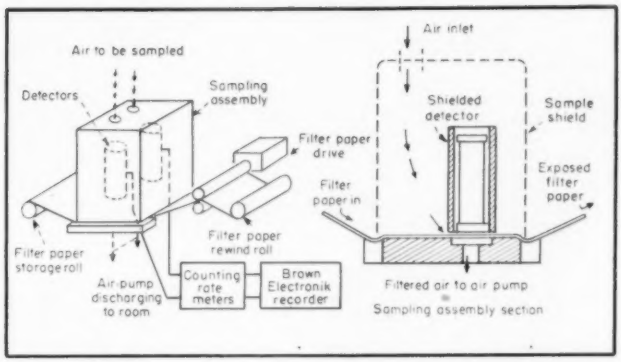


FIG. 2. Sampling assembly, showing path of filter paper and air flow through the hood containing detectors

Continuous Air Monitor

By T. H. MANSFIELD
Western Division, Tracerlab, Inc.
Berkeley, California

To provide a record of airborne particulate radioactivity, a continuous air monitor has been designed that counts the activity almost immediately after the dust is deposited on a moving strip of filter paper. A dual-channel system utilizing two detectors and two counting-rate circuits feeding a Brown Electronik Strip Chart Recorder makes it possible to record both the alpha and beta activity simultaneously.

The equipment, housed in a $3\frac{1}{2} \times 2\frac{1}{2} \times 3$-ft high cabinet, is shown in Fig. 1. The sampling mechanism is diagrammed in Fig. 2.

Air is drawn through two sampling ports, each 2 in. in diameter, at either $5\frac{1}{2}$ or $2\frac{3}{4}$ ft³/min, by an air pump located beneath the sampling assembly. Other flow rates can be obtained with different pumps. Filter paper is drawn past the sampling ports at a basic feed rate of 3.7 in./hr. Change gears in the drive mechanism provide variation of the feed rate by factors of $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, and 4.

Type H-70.009W filter paper, manufactured by Hollingsworth and Vose Co., East Walpole, Mass., is used. This material has a high particulate collection efficiency, reasonably small resistance to air flow at 100 to 500 ft/min, and is thin enough that the absorption by the paper of radiation from particles that penetrate into the paper is limited.

The sampling assembly is covered by an aluminum hood with two intake ports. Since the pressure inside the hood is about equal to the ambient air pressure, little air flows through the openings through which the filter paper passes.

Detectors and Circuits

Two detectors are mounted so that they scan the sections of filter paper through which the air is being drawn. The beta detector, a Tracerlab TGC-1 G-M tube, is shielded with lead to minimize the effect of radiation from previously exposed filter paper. The alpha detector, a P-12 scintillation probe, does not require shielding.

Pulses from the detectors are fed into two separate counting-rate circuits. Each circuit consists of two pulse-shaping multivibrators and a detector. Output from each detector is fed to the recorder. Full-scale ranges of 200, 2,000, and 20,000 cpm are normally provided.

A calibration signal derived from line frequency can be applied to the circuits to check operation. Aural monitoring is also provided.

Including high-voltage supply for the detectors, and blower motor, the unit uses 1 kw at 110 volts.

Modifications

To measure activity at a remote point, tubes can be connected to the air inlet ports. If two different locations are to be monitored, a divider can be placed in the sampling compartment.

It is possible to mount detectors to scan the filter paper some time after the sample is taken. This allows decay measurements to be made, but only for short-half-life activity.

Sensitivity

The sensitivity of the equipment depends upon both the sampling rate and the velocity of paper travel. The maximum sampling rate is limited by the capacity of the air pump and by the allowable pressure drop across the filter. The pressure drop across the filter can be decreased by increasing the size of the sampling port.

Increasing the length of the port increases the time to record a sudden increase in concentration. Increasing the width of the port, however, results in increased sensitivity without any decrease in speed of response.

Decreasing the paper speed increases sensitivity to low dust concentrations, but also increases response time.

With this apparatus, response times as short as 2 or 3 minutes and sensitivities of about $\frac{1}{10}$ allowable concentrations of radioactive dusts are obtainable, but the ultimate of both characteristics cannot be achieved at the same time.

Rapid Determination of I^{131} Excretion Curves for Human Beings

By FRANK E. HOECKER* and HOMER L. HIEBERT†

The clinical administration of radioactive iodine, I^{131}, for diagnostic purposes has become a routine procedure in many institutions. It is likely to replace the basal metabolism test where proper facilities and personnel are available. It is to be regretted, however, that the reduction of the method to a simple, routine procedure has been accomplished in some instances by sacrificing excretion studies and the valuable diagnostic information obtained from them.

In spite of the considerable evidence‡ of the unique information to be gained from iodine excretion studies, the time-consuming nature of the usual assay measurements has to some extent justified their abandonment. It is debatable, however, whether the deliberate disregard of tests which not only yield a great deal of decisive diagnostic information, but which also may betray unsuspected cancer cases, can be reasonably justified. The writers are convinced, on the basis of their own experience as well as that of other workers, of the unique value of excretion studies. This statement applies in particular to the continuous determination of the rate of excretion over a period of 48 hours after administration. This method is based on the assay of the percentage of the total dose in each specimen of urine excreted during the period of study. From these data, an "excretion curve" is plotted from which the rate of elimination as well as the ultimate total may be obtained.

The obvious diagnostic value of the excretion curve has led the writers to devise an assay method which has greatly reduced the time required for the assay of the numerous specimens which must be handled during the period of study. The simplicity of the method and apparatus make it readily usable by laboratory personnel of very limited training.

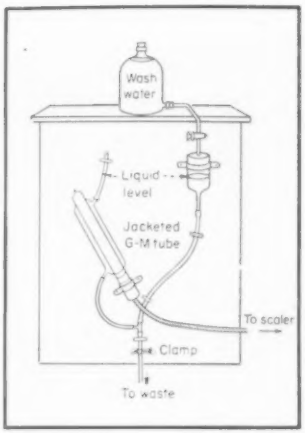
The method makes use of a thin-walled, jacketed G-M tube.§ The tube walls are sufficiently thin that beta particles from the iodine give enhanced counting sensitivity. The jacket has a definite volume (3 ml) which, when filled with solution, automatically insures that the same identical volume of all samples is assayed.

Since the Geiger tube is small (length of sensitive region about 0.7 cm, annulus thickness 1 mm) and is mounted on a three-pronged base, it may readily be mounted in a position making an angle of about 30° with the vertical by plugging it into a rigidly mounted socket, as shown in the illustration. When so mounted, the inlet tube is at the bottom of the jacket and is attached by means of rubber tubing to one branch of a glass T tube. The T tube is also connected to a waste bottle on the floor and to a glass U-shaped funnel upon which a fluid-level line is marked. The only pinch cock needed is placed in the waste line.

An open-ended transparent plastic tubing about 6 inches long is attached to the outlet tube at the upper end of the jacket. This serves to eliminate bubbles from the jacket when it is being filled through the lower tube. No overflow of liquid is ever permitted because the upper end of the relief tube is above the upper rim of the filling funnel.

Method

In normal use, a previous sample of fluid is drained from the apparatus just prior to a measurement, and it is necessary to flush the apparatus. The funnel is given a preliminary rinse with the pinch cock open. The pinch cock is then closed and the funnel is filled. This permits the fluid to flow into the jacket of the G-M tube.



APPARATUS for determining I^{131} excretion

To flush the jacket, the pinch cock is opened, and the Bernoulli effect in the T tube, caused by fluid flowing from the funnel, sucks the fluid out of the jacket very rapidly. No fluid will flow into the jacket until the pinch cock is closed. The flushing of the jacket is repeated four or five times until the fluid level in the funnel is at the fluid-level line. The same total amount of fluid is thus used for each measurement, and gamma radiation from the fluid in the funnel will make a proportionate contribution to the count obtained with any sample. Hence no error is introduced and the funnel may be as close to the G-M tube as desired.

Calibration. The apparatus is calibrated with solutions that are carefully prepared dilutions of the dosage administered to patients. The dilutions used to cover the range normally encountered in assays are 0.1, 0.05, 0.025, and 0.01% of the original dose per cubic centimeter of solution.

From the counting rates obtained from these solutions, the average counting rate for any given percentage solution can be determined. From this the total percentage of the original dose contained in a given unknown sample can be determined. It is convenient to express this in terms of the percentage of the original dose contained in 100 cm^3 of the solution. This might be called a dose per cent solution.

One further simplification can be

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† Department of Radiology, Stormont-Vail Hospitals, Topeka, Kansas.
‡ H. S. Hayden, K. E. Corrigan, Diagnostic use of radioactive tracers, *Harper Hospital Bulletin* **6**, No. 1 (February, 1948).
§ Radiation Counter Laboratories, Chicago, Illinois, Mark 1, Model 70

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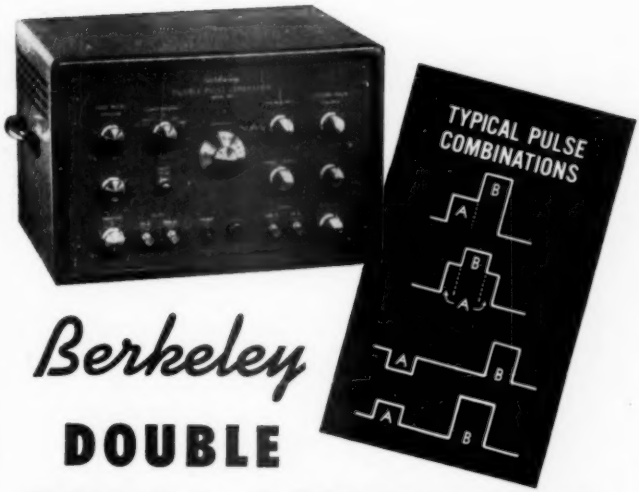
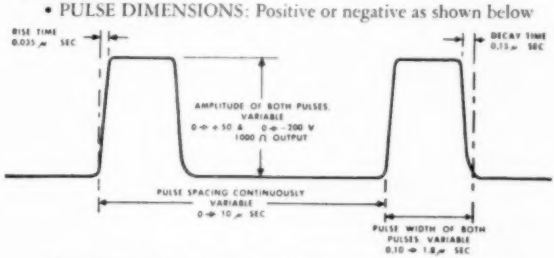


Berkeley DOUBLE PULSE GENERATOR

DESCRIPTION: The Berkeley Model 903 Double Pulse Generator is a general-purpose laboratory instrument that produces either single or paired pulses. Pulses are individually variable in width, amplitude, and spacing. Pulse polarity is individually selectable. Separate connectors provide impedance levels of 50 or 1,000 ohms for each pulse output.

SPECIFICATIONS

- PULSE DIMENSIONS: Positive or negative as shown below


RISE TIME
0.035 μ SEC
DECAY TIME
0.15 μ SEC
AMPLITUDE OF BOTH PULSES VARIABLE
0 → ± 50 & 0 → 200 V
1000 Ω OUTPUT
PULSE SPACING CONTINUOUSLY VARIABLE
0 → 10 μ SEC
PULSE WIDTH OF BOTH PULSES VARIABLE
0.10 → 1.8 μ SEC

- REPETITION RATE: Internally or externally controlled, 1 to 1,000 cycles. Push button single cycle.
- CALIBRATION ACCURACY: Separation dial, ±5% over entire range.
- INPUT POWER: 105 to 125 volts, 60 cycles, 90 watt.
- DIMENSIONS: 14¼" x 9¾" x 10¾"; panel, 8" x 13".
- NET WEIGHT: 18¼ lbs.
- PRICE: $440 F.O.B. factory.

TYPICAL APPLICATIONS: Checking characteristics of high-resolution electronic circuits, gates, switches, wide-band amplifier, measurement of resolution time of counting circuits, etc.

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made. Since only the total percentage of the original dose contained in a given specimen is of interest, and since the total amount of fluid excreted at one time is largely a matter of chance, the calculations and record keeping are simplified if each specimen is arbitrarily diluted to a given total. This is facilitated by use of 500-cm³ graduated specimen-collecting flasks of the type used for intravenous administration of fluids. Experience has shown that patients rarely excrete more than 500 cm³ at one time; this amount was therefore taken as the base volume. When this procedure is followed, it is unnecessary to measure the volume excreted, and the base volume enters the calculation of the percentage in the specimen only as a constant.

This constant-volume procedure necessitates a somewhat longer counting time on samples which have small excreted volumes, but this slight loss of time is more than compensated by the increased efficiency of the jacketed-tube assays and by the simplicity and rapidity of the manipulations and calculations.

Repeated tests have convinced us that subsequent assays are not measurably contaminated by previously assayed samples. There is no increase in the background of the tube even after 40 or 50 samples have been assayed.

In a typical case, the background of the tube is approximately 40 cpm. When a sample containing 0.01 dose per cent of the administered dose is in the jacket, a net count of 326 cpm is obtained. The percentage of the dose in any specimen is then obtained from the simple relation (net cpm × 5/326) × 0.01 = 1.53 × 10^{-4} × net cpm = percentage of dose.

Speeding Up and Improving Contrast of Thyroid Scintigrams

By LAWRENCE CURTIS* and BENEDICT CASSEN

Atomic Energy Project, School of Medicine, University of California at Los Angeles West Los Angeles, California

A series of papers (*1–5*) have appeared describing the instrumentation development, clinical testing, and clinical utility of an automatically scanning and recording gamma scintillation localizer. It has been proposed to call this device a "scintiscanner" and the visual record of radioiodine distribution obtained a "scintigram."

Figure 1 shows a typical scintigram of the enlarged thyroid gland of a diffuse hyperthyroid patient. The time required to obtain this scintigram was about 40 minutes. It is plain that a large fraction of this time is required to scan the background. If the background could be scanned more rapidly than the active gland area, the total time required to work with the patient could be materially reduced. Furthermore, if a signal could be obtained to distinguish between the background and the active area, this signal could be used to operate a relay to open the circuit of the printing relay and thereby prevent the printing of the background. Then the contrast could be increased.

A study of the possibilities of obtaining the distinguishing signal led to the very simple idea of feeding the incoming pulses to an auxiliary ratemeter circuit so that if the rate was below a certain critical preset value the printing relay circuit would be opened and the scanning motor would be speeded up. When the rate exceeded the preset value the scanning motor would be slowed down by a factor of about three and the printing relay circuit would be closed. By choice of a suitable time constant in the ratemeter circuit, much jitter in transition zones could be eliminated.

The circuit developed to perform these functions is shown in Fig. 2. Figure 3 is a scintigram obtained on the same patient at about the same time as Fig. 1, using the new equipment. The time taken to obtain this scintigram was about 30 minutes. The full possibilities of time saving are not indicated, however, as the scanning motor was adjusted to go slower than usual over the active region.

* * *

This article is based on work performed under contract AT-04-1-GEN-12 between the U. S. Atomic Energy Commission and the University of California at Los Angeles.

BIBLIOGRAPHY

1. B. Cassen, L. Curtis, C. Reed, NUCLEONICS **6**, No. 2, 78 (1950)
2. B. Cassen, L. Curtis, C. Reed, R. Libby, NUCLEONICS **9**, No. 2, 46 (1951)
3. H. C. Allen, Jr., R. Libby, B. Cassen, *J. Clin. Endocrinol.* **11**, 492 (1951)
4. F. K. Bauer, W. E. Goodwin, R. Libby, B. Cassen, *J. Lab. Clin. Med.* **39**, 153 (1952)
5. W. E. Goodwin, F. K. Bauer, T. Barrett, B. Cassen, *Am. J. Roentgenol. Rad. Ther. Nuclear Med.* (in press)

* PRESENT ADDRESS: R. C. Scientific Instrument Co., Playa del Rey, California.

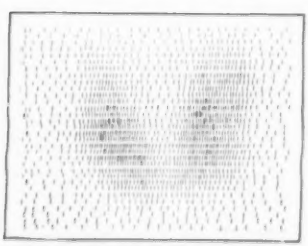

FIG. 1. Scintigram of diffuse hyperthyroid gland obtained by usual method

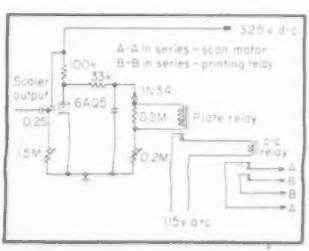

FIG. 2. Ratemeter and relay circuits used to obtain improved contrast in scintigrams

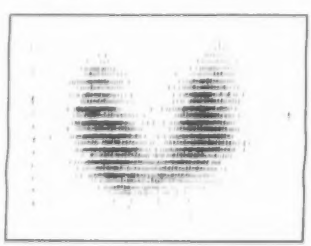

FIG. 3. Scintigram of same thyroid gland as in Fig. 1. Note improved contrast

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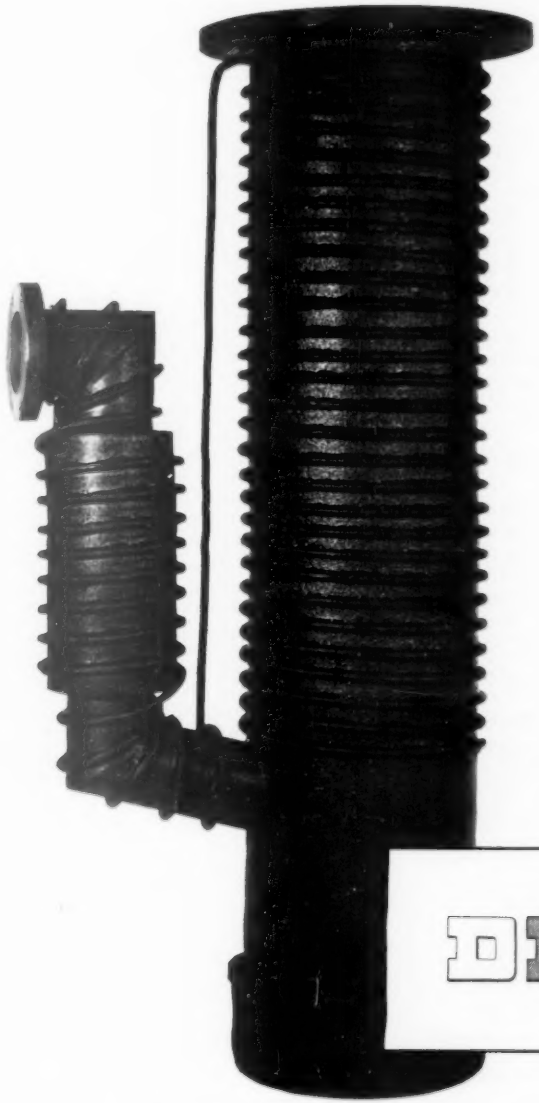

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BOOKS

Miscellaneous Physical and Chemical Techniques of the Los Alamos Project (Experimental Techniques)

Div. V, Vol. 3, of National Nuclear Energy Series, edited by ALVIN C. GRAVES and DAROL K. FROMAN (McGraw-Hill Book Co., Inc., 1952, xiii + 323 pages, $4)

Reviewed by BERNARD T. FELD, Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

This is regrettably the last of three volumes on "Experimental Techniques," summarizing work at the Los Alamos Laboratory during World War II. The first two of the series, "Electronics" by Elmore and Sands and "Ionization Chambers and Counters" by Rossi and Staub, have already clearly established their positions as leading textbooks in their respective fields.

This volume, while generally maintaining the high standards set by its progenitors, is not likely to be so universally useful, since it consists of six relatively short monographs (chapters) on essentially unrelated subjects. Some of these (e.g., ch. 3 and 6) are of a highly specialized nature; however, the physicist, chemist, or engineer who has occasion to require these techniques will be grateful for the wealth of detail included in their description.

The following are the chapters and subjects covered:

1. Preparation of foils (R. W. Dodson, A. C. Graves, L. Helmholz, D. L. Hufford, R. M. Potter, and J. G. Povelites). This is essentially a cookbook for the preparation of foils (thin and thick) of boron, thorium, uranium, and the transuranic elements.

2. Neutron sources (A. C. Graves, R. L. Walker, R. F. Taschek, A. O. Hanson, J. H. Williams, and H. M. Agnew). A very useful collection of data, some of which has already appeared in print [e.g., monoenergetic sources, *Revs. Mod. Phys.* **21**, 635 (1949)] is offered in this chapter. The section on the intercomparison of sources should prove especially useful to neutron physicists. It seems unfortunate that more material was not included on the excellent techniques used at Los Alamos for the absolute calibration of neutron sources. This chapter also includes a useful section on slow neutron detection, especially by BF_3 proportional counters.

3. The modulated betatron (D. Kerst). A description is given of a technique for producing single pulses of less-than-one-microsecond duration from a ~20-Mev betatron.

4. Modulation and other techniques used with ion accelerators (B. D. McDaniel, L. S. Lavatelli, and E. Graves). Techniques are summarized here for modulating cyclotrons, Cockroft-Walton generators, and Van de Graaff accelerators, with a wealth of experimental details and circuit diagrams included. While the slow neutron monochromater described may not be of the most advanced design, the material included on this and other techniques should prove of great usefulness to persons engaged in experiments with particle accelerators.

5. Topics on vacuum technique (T. Snyder and D. Lipkin). A great deal of useful information is given in this section on various problems associated with the ubiquitous problem of achieving a high vacuum.

6. Optical methods and instruments (J. E. Mack). This is mainly a description of optical instruments available for a number of special types of problems, including high-speed photography (resolution better than 10^{-4} sec), cathode-ray-oscilloscope photography, and high-time-resolution spectroscopy, with a discussion of techniques for their use.

Radiocarbon Dating

By WILLARD F. LIBBY (The University of Chicago Press, Chicago, Ill., 1952, vii + 124 pages, $3.50)

Reviewed by DON M. YOST, Gates and Crellin Laboratories of Chemistry, California Institute of Technology, Pasadena, Calif.

This book, because of its fundamentally important content and pleasant brevity, will rank high among the greatest of our century. The author, together with his few co-workers, has made the highly significant discovery that small, steady-state amounts of radioactive carbon-14 exist in the earth's atmosphere, and they have devised an ingenious apparatus for measuring the low level activity. They then applied the discovery, the attendant principles and theory, and the apparatus to the objective determination of the ages of many ancient, carbon-containing historical specimens, both Holy and mundane.

Dr. Libby's book, which is clearly and simply written, will prove a delight both to the layman and the learned who find interest in science, history, anthropology, and archeology.

On the physical and chemical side, the phenomena and principles involved in radiocarbon dating are, in the main, easily described. Cosmic rays, streaming towards the earth with a constant average intensity, interact with the nuclei of upper atmospheric gases. These interactions result in the formation of fast neutrons which are soon slowed down, by collisions with air molecules, to the thermal range and are then fairly easy prey for capture by nitrogen-14 nuclei. But soon after a capture, the new, overburdened nitrogen nucleus must, to avoid the ire of the nuclear physicists, toss overboard a proton and become radioactive carbon-14. The radiocarbon thus formed, whose half-life is $5{,}568 \pm 30$ years, is oxidized by the air to carbon-14 dioxide, and the ever-restless winds and seas play their role in maintaining a constant though small concentration of the carbon-14 dioxide at the earth's surface, where the much more abundant and chemically similar carbon-12 dioxide is also present.

Both kinds of carbon dioxide enter, on nearly equal footing, into the growth and living processes of plants, creatures, and man himself. Once the growth and living processes are brought to an end, by either natural or accidental means, the carbon-14 content decreases exponentially with time and with the half-life noted above. If, then, the specific activity of the carbon from a currently growing part of a plant or creature is measured, as well as that of some ancient specimen, it is comparatively easy to calculate the age of the specimen.

It is self-evident that the discovery is of vast and inspiring scope. It calls upon our present knowledge of modern physics, cosmic rays, chemistry, plant and animal life, and upon both written and undocumented history; and then it plainly indicates the way to further explorations in several directions.

That many of the details involved in radiocarbon dating will be repeatedly studied and refined there is little doubt. Laymen, amateurs, and the major and minor poets in their quiet ivied halls

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In its longest chapter, the book contains an impressive list of specimens and samples that have been dated by the radiocarbon method. They range in variety from the recently discovered Dead Sea Scrolls of the Book of Isaiah (1917 ± 200 years old) through mummiform coffins, once-sturdy roof beams, shells, tree rings, rope, wheat and barley grain, bones, charcoals from ancient encampments and cottage hearths, to the remains found in unswept caves which long ago provided shelter for man or wild life.

The specimens whose ages were measured range from 20,000 to some 600 years old. They cover, therefore, periods in history beyond memory or written record, on through many civilizations, dynasties, and empires, to the periods of which Homer and Vergil sang, to the golden age of Pericles, until we come to that sharp break in history when the western world, weary of strife and Caesars, found comfort and unity in the letters of Saint Paul. Still further, the dating method takes us down through the days of Genghis and Kublai Khan and the inquisitive Marco Polo, to the Renaissance in Europe, and almost, but not quite, to the time when Columbus discovered a new and freer part of the world. The historical scene which the dating method presents to us is too large, unexplored, and detailed to be adequately chronicled in a dozen volumes, much less in a single column or page by this reviewer.

The seventh and last chapter, by Dr. Fredrick Johnson, presents an excellent and scholarly discussion of the significance of radiocarbon dating to archeology and geology. The information, admonitions, and good counsel which he offers deserve the careful attention of those embarking on this new field of endeavor.

There are serpents among reviewers who deem it their inherent privilege to arm a bow with an arrow dipped in venom, to whet both edges of a pointed blade, and then to submit the author and his book to both perils. Because Dr. Libby's book so obviously transcends, in concept and horizon, such petty foul play, this reviewer, who isn't a perfectionist anyway, would count it as churlish to quibble over the very minor errors in spelling or printing. For here on the Pacific's shores, long sanctified by the labors of a robed Franciscan dedicated to a noble purpose, when friends speak gaily, or in whispers, of gold and brigands, of atoms and their many, many secrets, of dates, discoveries, and the manifest destiny of Charlie McCarthy, of mink, of arms and men, of confusion and discouragements, there always persists the memory of past accomplishments and future hopes so well accented in a simple verse by Joaquin Miller:

Then pale and worn, he paced the deck,
And peered through darkness. Ah, that night
Of all dark nights! And then a speck—
A light! A light! At last a light!
It grew, a starlit flag unfurled!
It grew to be Time's burst of dawn.
He gained a world; he gave that world
Its grandest lesson: On! Sail on!

Principles of Geochemistry

By BRIAN MASON. (John Wiley & Sons, Inc., New York, 1952, ix + 276 pages, $5)

Reviewed by J. LAURENCE KULP, Lamont Geological Observatory, Columbia University, Palisades, New York

Prior to the publication of "Geochemistry" by Rankama and Sahama (University of Chicago Press) in 1949, there was no comprehensive treatment of the distribution of the elements in the earth in the English language. The classic work of Goldschmidt which provided the scientific basis for this phase of geochemistry was scattered through many obscure journals. Despite the excellence of the Rankama-Sahama text, the rapid development and utilization of geochemistry left much to be done.

Dr. Mason's book thus is a welcome addition to the subject. Instead of being an encyclopedic work on the distribution of the elements, the "Principles of Geochemistry" attempts to survey the basic concepts on the whole subject of geochemistry. While written as a textbook on a first-year graduate level, it is a carefully digested, up-to-date synthesis of the present status of knowledge of the chemistry (and physics) of the earth.

It should be valuable to chemists and physicists who would like to see how their disciplines have been applied to earth science or to the geologist who is looking for principles to integrate his complex array of facts.

BOOKS RECEIVED

Philosophic Problems of Nuclear Science, by Werner Heisenberg, Pantheon Books Inc., New York, 1952, 126 pages, $2.75.

Between 1932 and 1948, Nobel Laureate Heisenberg delivered eight lectures that have been translated and collected under the title above. A more careful examination of the subjects discussed suggests the book might more appropriately have been entitled "Philosophic Problems of Modern Physics." He uses historical perspective in a learned plea for science as a means toward international understanding.

A Student's Radiological Mathematics," by L. A. W. Kemp, Blackwell Scientific Publications, Oxford, England (and Charles C Thomas, Springfield, Ill.), 1951, xii + 315 pages, $5.

The author has employed a light touch and simple diagrams to make what he calls "elementary mathematics applied to medical radiology" seem like a fascinating tool. He seeks to interest the doctor whose dusty memory of college math prevents a more knowledgeable grasp of radiographic problems, the radiologist who will be dealing with dosage calculations for radioisotopes in therapy and diagnosis, and, of course, the medical student. The inclusion of problems and answers makes the book a useful text and good refresher reading.

Practical Radiography for Industry, by H. R. Clauser, Reinhold Publishing Corporation, New York, 1952, x + 301 pages, $7.50. *(To be reviewed.)*

The Origin of Life and the Evolution of Living Things, by Olan R. Hyndman, M.D., Philosophical Library, New York, 1952, xxi + 648 pages, $8.75.

An environmental theory is offered which is in opposition to the current teaching that fortuitous mutation is the fundamental mechanism of evolution. The author seeks to explain the origin and evolution of living organisms on a physico-chemical basis and as expressions of the operation of natural law.

Ultrasonic Physics, by E. G. Richardson, Elsevier Press, Houston, Texas, 1952, x + 285 pages, $5.

A great portion of this book deals with the construction and use of ultrasonic interferometers as precision instruments for physicist and physical

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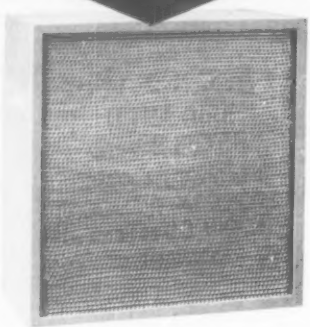

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chemist. It discusses, in particular, sources of ultrasonics, methods of detecting the radiation, measurements of propagation constants, propagation in gases, liquids, and solids, theories of anomalous propagation, and ultrasonics in disperse systems.

Advanced Statistical Methods in Biometric Research, by C. Radhakrishna Rao, John Wiley & Sons, Inc., New York, 1952, xvii + 390 pages, $7.50.

The author, a professor of statistics at the Indian Statistical Institute in Calcutta, has drawn many of his examples in this book from his experience in the field of biometric research, but the methods and formulas would seem to apply equally well to economics, sociology, and other fields. The book is a treatment of the theory of multivariate analysis.

The Initiation and Growth of Explosions in Liquids and Solids, by F. P. Bowden and A. D. Yoffe, Cambridge University Press, New York, 1952, xii + 104 pages, $4.50.

This is one of the Cambridge Monographs on Physics. It is an experimental inquiry into the question "How is the mechanical energy of the blow or of rubbing able to produce the chemical excitation which leads to explosive reaction?" With work still in progress by the authors, the answer is necessarily incomplete and elementary, but the experiments described suggest a mechanism which indicates that, for the majority of explosives, the initiation is thermal in origin.

OTHER LITERATURE

Harwell, the British Atomic Energy Research Establishment (1946-1951). It is unfortunate that this, the first report to the British Empire and the world of the fine work being done at Harwell, in England, has had to be told as a short story (128 pages)—it deserves fuller treatment. Making a choice of what to write about from the great variety of Harwell accomplishments must have been a difficult job; those responsible for its preparation, are to be complimented on the outcome. There is much to interest both layman and scientist in its paper-bound text and the fine photographs and diagrams accompanying it. Chapters are devoted to Harwell's production, isotope, reactor, accelerator, and health-physics programs, and to an account of some fundamental research work completed or in progress. One appendix tells more about the Harwell reactors; three others are devoted to lists of staffs and their scientific papers and to a glossary and reading list. *H.M.S.O., London, or British Information Services, 30 Rockefeller Plaza, New York 20, N. Y., $1.40.*

Neutron Cross Sections (AECU-2040). A tabular and graphic compilation of neutron cross section data covering the energy range from 0.0001 ev to 100 Mev. A critical evaluation of existing data based on both published and unpublished values is offered by the Atomic Energy Commission's 12-man Neutron Cross Sections Advisory Group which made the document available. Thus the data presented are considered the weighted "best values" of several types of cross sections. Besides 16 pages of introductory and tabular matter, this paper-bound document contains 184 graphs, all on 11 × 17-inch sheets. *Office of Technical Services, Dept. of Commerce, Washington 25, D. C., $1.*

Selected Readings on Atomic Energy. A 23-page list of official publications, books, and magazines for both the general and advanced reader, including material published up to May 1, 1951. It was compiled by the U. S. Atomic Energy Commission. *GPO, Washington 25, D. C., $0.15.*

27 Questions and Answers about Radiation and Radiation Protection. This is one of a series of leaflets which the U. S. Atomic Energy Commission is putting out to answer briefly some of the more frequent questions asked by laymen about radioactivity. Examples: "Is it safe to live near atomic energy plants? How can people work safely with radiation?" *GPO, Washington 25, D. C., $0.15.*

Radioactive Atoms and Isotopic Tracers, by Joseph W. Kennedy. This is a paper-bound, mimeographed, collection (89 pages) of the 26th Annual Priestley Lectures given in April, 1952, at the Pennsylvania State College. Dr. Kennedy, who is chairman of the department of chemistry of Washington University, St. Louis, Mo., discussed nuclear transformations, uranium, fission, transuranium elements, isotopic tracers, electron transfer reactions, quantitative kinetic studies with tracers, and self-diffusion of

aqueous ions. *Phi Lambda Upsilon, The Pennsylvania State College, State College, Pa., $2.*

Medical Aspects of Civil Defense. A collection of ten special articles reprinted from the *Journal of the American Medical Association*, bound under a single cover for ready reference. There is much good medical advice in its 130 pages on how to plan for treatment of injuries, both mental and physical, resulting from air raids. Atomic, bacteriologic, and chemical warfare are all considered. *Council on National Emergency Medical Service, American Medical Association, 535 North Dearborn St., Chicago 10, Ill., $0.25 for a single copy, $0.20 for 100 or more.*

Fission Product Utilization (BNL 171). A collection of papers and discussions at the recent conference on fission products sponsored by Brookhaven National Laboratory, Feb. 18–19, 1952. *Office of Technical Services, Dept. of Commerce, Washington 25, D. C., $0.25.*

Report of the NRC Committee on the Measurement of Geologic Time, 1950–1951. A 140-page, paper-bound, annual publication of the National Research Council's Division of Geology and Geography. It covers recent work in the determination of isotope ratios and discusses other aspects of the problems of dating rocks, etc., by their radioactive contents. An annotated bibliography is included. *Publications Office, National Research Council, 2101 Constitution Avenue., Washington 25, D. C., $1.*

Tables for the Analysis of β-Spectra (National Bureau of Standards Applied Mathematics Series 13). Values of the so-called "Fermi Function" comprise the major part of this 61-page pamphlet, which also includes auxiliary tables, figures, and graphs, and an introductory discussion of beta spectra by U. Fano of the NBS Radiation Physics Laboratory. *GPO, Washington 25, D. C., $0.35.*

Titan—System No. 47 (Gmelin Handbuch). A 511-page volume containing comprehensive data on titanium, its alloys, and compounds. An index to the world's literature on titanium up to January 1, 1950, is included. The American booksellers for this volume are: *Walter J. Johnson, Inc., 125 East 23d St., New York, or Stechert-Hafner, Inc., 31 East 10th St., New York, $27.20.*

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NUCLEONIC EVENTS

AEC May Build Dual-Purpose Central-Station Nuclear Power Plant in Nevada

The world's first central-station nuclear power plant may be built in Nevada by the Atomic Energy Commission. Action by the AEC is awaiting the analysis by the agency of a feasibility report submitted by the Nevada Atomic Power Utilization Committee. Interest in the area comes from the fact that no cheap power is available to mining and other interests there. If AEC builds a dual-purpose reactor—to produce electric power and plutonium—the price it could charge for the power would be much less than present prices.

Proposed site for the nuclear power plant is at the Richmond Eureka Mine of Eureka Corporation, Ltd., 22 miles from Eureka, Nevada, where absence of cheap industrial power has halted operations in mining an estimated $175-million worth of gold, silver, lead and zinc ores.

Need for Cheap Power

The mine management finds that its present Diesel-power system is too costly to enable the firm to carry out its mining operations because of a large flow of water.

Nevada sponsors of the commercial nuclear power plant say that energy from the plant could be used in dewatering the mine as well as in pumping ground-water for irrigation in the several adjacent arid valleys.

At present Eureka is paying three cents per kwh for Diesel power. Although the firm hasn't announced what it would be willing to pay for nuclear power, it feels that such power could be furnished for less than the three-cent figure and at the same time give the AEC a rate in excess of what could be paid by large commercial firms in populous centers where industrial power is cheaper.

Nevada Committee Chairman A. M. Smith forwarded the feasibility report to Marion Boyer, general manager of the AEC, for consideration following a request for such information from L. R. Hafstad, director of reactor development for the AEC, at a July meeting in Reno, attended by members of the committee and Senator George Malone, Nevada.

Hafstad, according to Smith, said that a new reactor definitely would be constructed by the AEC somewhere in the United States as soon as possible for the manufacture of plutonium and that electrical energy would be a by-product which would be sold as profitably as possible as a credit to the cost of plutonium.

In brief, the 13-page feasibility report sums up the history of the Eureka district and the potentialities that could be developed only if there was a source of cheap power.

Eureka, in central Nevada, is approximately 400 miles north of Hoover and Davis Dams, source of the cheapest power in the state.

Summary of Report

The report points out:

That the location is in a great desert area with little population.

That there are good transportation and communication facilities.

That the district is one of the most attractive potential gold-silver-lead-zinc producing areas of the United States. Recent development of a large body of ore in one mine alone apparently will justify installation of a dual-purpose reactor to supply power.

That the Diesel power, the only power presently available, costs three cents for each kwh.

That disposal of radioactive wastes from the reactor should be a minor problem because of favorable location. (The mine, at 7,000 ft. altitude, is 500 ft. higher than the town of Eureka.)

That the financial backing of the Eureka Corp. is strong and it would make a longterm agreement.

That the Eureka Corp. has facilities for construction operation and management of a reactor power plant and a 6,000-kw power plant ready for immediate operation.

That initial experimentation could be carried on without interference, and all state agencies would cooperate to the fullest extent.

It is presumed that as soon as the AEC studies the preliminary report it may have a definite announcement as to whether to construct the plant at the Eureka site. Hafstad, who inspected the area with Senator Malone in June, was highly pleased with the possibilities.

Serving with Smith on the Nevada power committee are Roy A. Hardy of Reno, prominent Nevada mining man and University of Nevada regent; George W. Mitchell, general manager of the Eureka Mine, and the following from the University of Nevada: Dr. Joseph Moose, Dean Stanley Palmer and Dr. Vernon E. Schied.

Organized at the July meeting in Reno, at the request of Senator Malone, the committee has a five-fold purpose:

1. To prepare a feasibility report on the Eureka project, setting forth comparative costs with those of Diesel-electric and hydroelectric power.
2. To disseminate information throughout the state in regard to atomic energy and its use in various industries.
3. To arouse the interest of the mining industry and owners of mines located in areas of difficult and remote accessibility in the use of nuclear reactors to solve their power problems.
4. To promote educational programs in high schools in order to spread information regarding nuclear energy.
5. To support actively the program that has been initiated at the University of Nevada for the processing of low-grade uranium ores and to promote the adoption of additional studies covering effects of radioactivity on plant, animal and human lives.

Westinghouse to Design Large-Ship Reactor

Development work on a nuclear power plant suitable for propulsion of large naval vessels such as aircraft carriers will be conducted by Westinghouse Electric Corp. under a contract with the Atomic Energy Commission.

A prototype thermal reactor for submarine propulsion is currently being built by Westinghouse and Argonne National Laboratory at the Reactor Testing Station, Arco, Idaho.

The existing contract between Westinghouse and AEC has been modified

to include work on the new project. The work will be centered at the Bettis Plant near Pittsburgh, Pa.

Gaseous-Diffusion Plant to be Built in Ohio

A new gaseous-diffusion plant will be built by the Atomic Energy Commission on a 6,500-acre tract of land north of Portsmouth, Ohio. Preliminary design estimates indicate that the new plant will cost $1.2-billion. These funds were made available when Congress passed a bill for supplementary funds for atomic energy plant expansion (NU, Aug. '52, p. 74).

Portions of the plant will be placed in operation as soon as completed. Construction of the plant as a whole is scheduled to take about four years.

Power requirements for early operations will be about 400,000 kw, to be supplied from existing facilities. New power plants will be built to supply the maximum of 1,800,000 kw which will be needed when the entire plant is in operation.

Direct supervision of the construction and operation of the plant will be under a new Portsmouth Area Office which will be established by the Oak Ridge Operations Office of AEC. Kenneth A. Dunbar has been named area manager, and R. H. McCulloh deputy area manager. Local offices will be opened in Portsmouth.

The principal construction contractor is Peter Kiewit Sons' Co., Omaha, Neb. The operating contractor has not yet been announced.

Polonium-210 Now Available from Oak Ridge

Reactor-produced Po^{210} may now be purchased from Oak Ridge National Laboratory for research purposes. This is the first reactor-produced alpha emitter to be sold. It is also available as a neutron source.

For use as an alpha source it will be plated on a strip of platinum. For use as a neutron source it will be mixed with beryllium and enclosed in a nickel cylinder, $\frac{3}{4}$ in. in diameter.

Po^{210} is produced by neutron bombardment of bismuth, and is of higher purity than that derived from decay of radium.

Marking the anniversary of the isotope program, Oak Ridge announced that since August 2, 1946, more than 35,000 shipments have been made to users in 46 states and 33 foreign countries. Several thousand additional shipments have been made from other sources such as Brookhaven and Argonne National Laboratories and commercial concerns.

The demand for isotopes has been increasing yearly, and no indication of leveling off is apparent. In fiscal 1952, shipments totaled 9,000, about 25% of the shipments for the entire six-year program.

The largest selling isotope is I^{131}, about 10,000 shipments; next is P^{32}, about 8,000 shipments. In terms of activity, Co^{60} was first with about 2,200 curies, followed by I^{131} with 1,200 curies.

Goudsmit is BNL Physics Head; Reactor Dept. Split

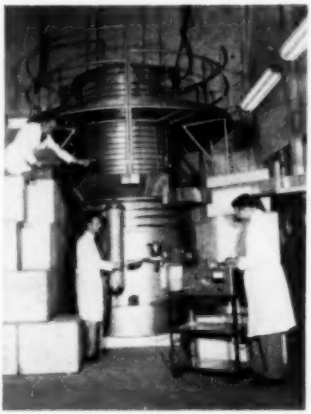
In an announcement last month of several staff changes, Brookhaven National Laboratory named S. A. Goudsmit chairman of the physics department, and split the reactor science and engineering department. Former reactor co-chairmen Marvin Fox and Clarke Williams will now head the newly formed reactor and nuclear engineering departments, respectively.

In addition, G. N. Glasoe was appointed associate chairman of the physics department to assist in administration of the experimental research programs. Dr. Lewis K. Dahl was appointed chief of the medical research service in the hospital of the medical department.

Goudsmit, a member of the Brookhaven staff since 1948, became acting chairman last year in place of T. H. Johnson, who was named director of AEC's Division of Research. Goudsmit, who is also editor of *Physical Review*, will be chairman for three years.

The new reactor department will operate the Brookhaven reactor, handle isotopes and special materials, and conduct research in neutron physics and shielding. The nuclear engineering department, in addition to carrying out reactor research and development, will be responsible for the hot chemistry laboratory and for the group in charge of developing methods of safe disposal of radioactive waste materials.

Both Fox and Williams joined the Brookhaven staff in 1946 to help in the design and construction of the research reactor. As a visiting scientist at Brookhaven last year, Glasoe supervised design and construction of the Laboratory's 18-in. cyclotron.



WATER-BOILER-TYPE REACTOR at North American Aviation's Atomic Energy Research Department, Downey, Calif., has its background radiation level measured. Concrete shielding blocks have been removed showing housing where graphite reflector and core are located. Superstructure is not part of reactor, but is a test unit for experiments and study in field of reactor development

Expansion Contracts Let for Three AEC Plants

Construction contracts for expansion of the Atomic Energy Commission's plants at Oak Ridge, Tenn., Paducah, Ky., and Hanford, Wash., have been awarded.

A $464-million addition to the gaseous-diffusion plant at Oak Ridge will be built by the Maxon Construction Co. of Dayton, Ohio. At Paducah, the prime contract on a $459-million addition to the U^{235} separation plant now under construction has been awarded to F. H. McGraw Co., Hartford, Conn.

At Hanford, negotiations have been completed with Kaiser Engineers for construction of a large part of the new expansion program of the plutonium project.

The funds for the expansion at Oak Ridge and Paducah, which are operated by Carbide and Carbon Chemicals Co., were provided for in the $2.9-billion supplemental appropriations bill passed in July (NU, Aug. '52, p. 74). Design and supervision of plant

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construction for these projects is being done by Giffels and Vallet, Detroit, Mich.

At Hanford, General Electric Co., operator of the plant, will furnish basic engineering design, and complete design for certain complex features of the expansion. The remainder of the design will be done by Vitro Corp., New York, N. Y.

New Senior Responsible Reviewers Appointed

Two old members have been retained, and four new members have been appointed to the committee of Senior Responsible Reviewers of the Atomic Energy Commission. The committee, whose membership up to now has been static, will operate on a rotation system, with one change in membership each year.

The Senior Responsible Reviewers are a statutory committee of AEC. They give technical guidance to the director of classification, not only for declassification, but also for the original classification of new information. They also operate when there is doubt on the part of the Responsible Reviewers as to the suitability of a classification or declassification recommendation. These recommendations are originally made by an official of the plant or laboratory where the information originated.

The two continuing members of the committee are W. C. Johnson, chairman, department of chemistry, University of Chicago; and J. M. B. Kellogg, physicist, and a division leader at Los Alamos Scientific Laboratory. The new members are: J. R. Richardson, physics department, University of California at Los Angeles; R. H. Crist, physical chemist, and research administrator, physical processes department, Carbide and Carbon Chemicals Corp., South Charlston, W. Va.; T. B. Drew, chemical engineer, Columbia University; and J. P. Howe, chemist, and head, metallurgical division, Knolls Atomic Power Laboratory.

The new committee holds its first meeting this month.

Radiological Safety Subject of NYU Course

A two-week course on radiological safety, beginning October 20, will be given by the New York University Post-Graduate Medical School in cooperation with the Atomic Energy Commission.

The course is designed for the instruction of industrial, governmental, and institutional people, including users of radioisotopes and X-ray equipment. It will be given at the Institute of Industrial Medicine of the Post-Graduate Medical School.

The lectures and demonstrations will cover the interaction of radiation with matter; the theory and instrumentation of radiation measurement; radiobiology; radiation dosage; uses of radiation in medicine, research, and industry; shielding; surveying and monitoring instruments; principles of radiological safety; and waste disposal.

The tuition fee is $50. Further

Raw Materials Developments

• **Uranium search.** The AEC has announced that it will aid private search for uranium-bearing ores by publicly releasing its airborne findings of radioactive areas.

• **Idaho.** The AEC has authorized limited expenditures to the Coeur d'Alene Mines Corp. for work on a uranium-bearing vein at the company's mine near Osburn. Costs incurred are repayable to the Government in the event that commercial uranium ore is developed.

• **Salt Lake City.** Vitro Corp. is completing a $1.1-million expansion program at its Salt Lake City, Utah, plant that will make possible milling of 300 tons of nonvanadium type uranium ores daily. The reduction center uses the acid-leach method. The regular operating schedule calls for an output of the uranium oxide from 200 tons, daily. The ore is supplied from AEC depots and stockpiles at Marysvale, Utah. Most ores are low-grade autunite.

• **South Africa.** Uranium production will be stepped up this year by the Rand Gold Mines, Johannesburg. Other mines are also expected to undertake uranium production.

• **Canada.** Extensive development is being done on a uranium deposit on the northern shore of Lake Athabaska, Saskatchewan. About 2,000 men are working on the project, and more than $8-million will be spent on the work during 1952.

course and registration information may be obtained from the Office of the Dean, New York University Post-Graduate Medical School, 477 First Ave., N. Y. 16.

Sen. Pastore Named to Atomic Energy Committee

Vice President Alben Barkley has announced the appointment of Senator John O. Pastore, Rhode Island, as a member of the joint Senate-House Committee on Atomic Energy. This fills the vacancy created when Senator Brien McMahon, Connecticut, died in July.

The committee, composed of nine Senators, and nine Representatives, will choose a new chairman. Senator McMahon, author of the atomic energy act, was chairman.

Meetings on Atomic Energy in Industry to be Held

A series of round-table discussions on atomic energy in industry will be sponsored by the National Industrial Conference Board. The meetings will be held on Oct. 16 and 17 at the Waldorf-Astoria Hotel, New York, N. Y.

The topics of the sessions are: sales opportunities in the atomic field; current uses of atomic by-products, which will be divided into meetings on applications in industry, agriculture and food products, and medicine and pharmaceutical products; and problems of industrial participation, which will be divided in meetings on labor-management problems, legal problems, power potentials of atomic energy, private investment for atomic power, economics of atomic power, and technical problems of atomic power.

The principal speakers will be: M. W. Boyer, general manager, Atomic Energy Commission; Harry Winne, vice president, General Electric Co.; William L. Davidson, director, office of industrial cooperation, AEC; Paul C. Aebersold; director, isotopes division, AEC; John C. Bugher, director, division of biology and medicine, AEC; Edwin J. Putzell, Jr., secretary, Monsanto Chemical Co.; Chauncey Starr, director, atomic energy research department, North American Aviation, Inc.; Walker L. Cisler, president, Detroit Edison Co.; and Lawrence R. Hafstad, director, division of reactor development, AEC.

There will also be a dinner session at which Philip Sporn, president, American

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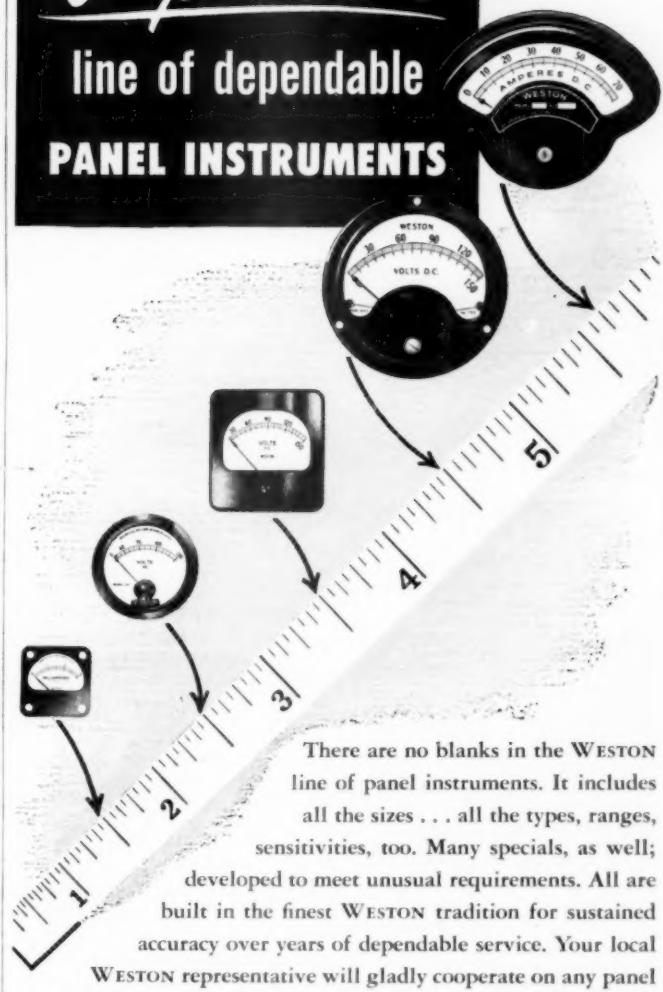

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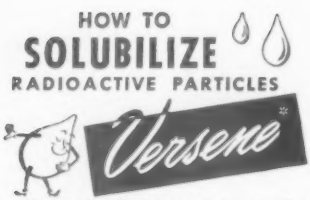

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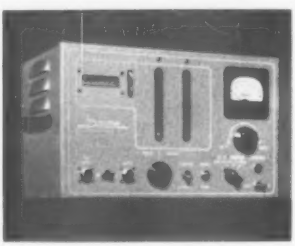

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Gas and Electric Service Corp., will speak, and a luncheon session at which David E. Lilienthal, first AEC chairman, will speak.

According to R. M. Ballinger of the division of business practices of the Conference Board, these meetings were arranged because it was felt that it is becoming increasingly important that more management officials be informed on the possibilities of the atomic energy field. This is the first of a series of annual meetings. It is hoped that in the future it will be possible and feasible to set up more frequent regional meetings in addition. The public is invited to the meetings.

Science Foundation Awards 29 Research Grants

The National Science Foundation has approved 29 additional research grants in the biological and physical sciences. This group of grants, totaling $263,535, is the last to be approved during fiscal 1952.

During the year 98 grants were made with stipends totaling $1.2-million. The grants were distributed to 60 institutions in 35 states and Hawaii.

The Foundation is attempting in its research support program to encourage development of research activities in smaller institutions throughout the country.

Research fields included in the latest group of grants are astronomy, chemistry, developmental biology, earth sciences, engineering, environmental biology, experimental psychology, genetic biology, mathematics, microbiology, molecular biology, physics, regulatory biology, and systematic biology.

IN BRIEF

• **Atomic power lab.** The Navy has begun construction of a $4.4-million radiological defense laboratory at Hunter's Point shipyard, San Francisco.

• **Radioactive mosquitoes.** Biologists plan to release more than 1,500,000 radioactive mosquitoes at Sanibel Island, Fla., as part of a study of the range and habits of mosquitoes.

• **Radioisotope course.** A course on advanced radioisotope techniques in biochemical research will be given at the Oak Ridge Institute of Nuclear Studies on Nov. 3–14, 1952. The first week will be devoted to C^{14}, and the second to other major isotopes. Application deadline is Oct. 1. Information may be obtained from R. T. Overman, Special Training Division, ORINS, Box 117, Oak Ridge, Tenn.

• **More cobalt bombs.** Six Co^{60} therapy units, produced in Ottawa by Eldorado Mining and Refining (1944) Ltd., are scheduled to be delivered this year to hospitals in Italy, Vancouver, Winnipeg, New York, and Chicago.

• **Research in Italy.** A National Council for Nuclear Research has been formed by decree of the Italian government. The Council, whose first president is Francesio Giordani, will have the functions of research in nuclear physics, coordination of efforts in that field, encouragement of application of atomic energy in industry, and cooperation with foreign nuclear research institutions.

• **Dutch cyclotron.** The Technical University of Delft, Holland, has started building a 500-Mev cyclotron. The accelerator, which will be the largest on the European continent, will be used to train Dutch nuclear engineers.

• **Israeli AEC.** A commission has been appointed in Israel to handle atomic research. The commission will deal with all aspects of atomic energy research.

• **Radiolanthanum for cancer.** Kurt G. Stern, Professor of Biochemistry at Brooklyn Polytechnic Institute, has reported encouraging results in cancer treatment by injection of La^{140}. Now in their third year, the studies are based on the affinity that nucleic acids have for lanthanum.

• **Radioisotopes committee.** An ad hoc committee composed of officials of AEC, Food and Drug Administration, and National Institutes of Health, has been formed to discuss problems in distribution and use of radioisotopes that overlap the jurisdiction of the three agencies. The committee will serve as a clearing house on problems in the uses and proposed uses of radioisotopes in food, feed, drugs, and instruments.

NUCLEAR NEWSMAKERS

Philip Miller has been appointed laboratory director of Walter Kidde Nuclear Laboratories.

Edward S. Spoerl has been promoted to biochemistry chief of the biology di-

vision at Mound Laboratory, Miamisburg, Ohio.

R. R. Tillotson has succeeded **A. G. Gleason** as manager of the Livermore Research Laboratory of AEC.

Mark M. Mills of the James Forrestal Research Center, Princeton, N. J., and **Harry Wexler,** chief, scientific services division, U. S. Weather Bureau, are new members of the Reactor Safeguard Committee, AEC. They replace **Benjamin Holzman** and **John A. Wheeler.**

Ralph A. Morgen, director of the engineering and industrial experiment station of the University of Florida, has been appointed to direct the research support program in the engineering sciences of the National Science Foundation.

F. A. Paneth, professor of chemistry at the University of Durham, Durham, England, was awarded the Lavoisier Medal of the Societe Chimique de France.

Oscar S. Smith is the new director of AEC's division of organization and personnel. He succeeded **Fletcher C. Waller.**

MEETINGS

American Chemical Society, 122d National Meeting—Atlantic City, N. J., Sept. 14–19

3d Instruments and Measurements Conference and Exhibition (includes Symposium on Methods of Measurement in Nuclear Physics and Radioactivity), Royal Swedish Academy of Engineering Sciences and Association of Technical Physicists—Stockholm, Sweden, conference Sept. 22–25, exhibit Sept. 23–30

American Association for the Advancement of Science (Alaska Division)—Mt. McKinley National Park, Alaska, Sept. 22–27

American Roentgen Ray Society—Houston, Tex., Sept. 23–26

National Electronics Conference—Chicago, Ill., Sept. 29–Oct. 1

4th International Heat Congress—Paris, France, Sept. 29–Oct. 4

International Council of Scientific Unions, General Assembly—Amsterdam, The Netherlands, Sept. 30–Oct. 3

American Physical Society, New York State Section—Cornell University, Ithaca, N. Y., Oct. 17–18

4th Inter-American Congress of Radiology—Mexico City, Mex., Nov. 2–6

National Academy of Sciences, Autumn Meeting—St. Louis, Mo., Nov. 10–12

American Institute of Electrical Engineers, Subcommittee on Electrically-Operated Recording and Controlling Instruments—Benjamin Franklin Hotel, Philadelphia, Pa., Nov. 17–18

American Standards Association, Annual Meeting—Waldorf-Astoria Hotel, New York, N. Y., Nov. 19

American Physical Society—Washington University, St. Louis, Mo., Nov. 28–29

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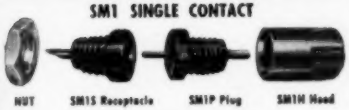

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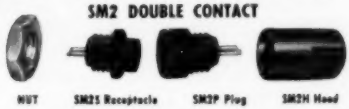

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LETTERS

British Functional Classification of Personal Dosimeters

DEAR SIR:

The May, 1952, NUCLEONICS (p. 86) contains a letter from W. A. Shurcliff suggesting a classification for personal dosimeters according to their function. He suggests two categories: (1) a "counseling dosimeter," whose prime function is to provide continuous information or counsel as to the wearer's dose, and (2) a "completion dosimeter," which provides information about the dose received at the end of some period of interest.

In Europe, and particularly in Great Britain, we have not felt the need for these new terms, partly because we have already agreed* to classify personal dosimeters as used in civil defense as (1) *flash dosimeters*, when they are required to measure the direct, immediate radiation dose received by the wearer from the explosion itself, and (2) *individual dosimeters*, when they are required for use by rescue workers and others who have to enter an area in which there may be residual radioactivity.

All our individual dosimeters are of the counseling type, and give a reading of the dose received from the time when the instrument was originally charged (and set to zero) up to the time of observation. If necessary, the individual dosimeter reading can be observed continuously, and this is obviously necessary, if the instrument is also to be used as a dose-rate meter (an official requirement for British radiac individual dosimeters). One aspect of special interest is that these instruments have a range of 0–50 or 0–75 r, and their natural leakage is about 1% per 24 hours. Hence, it is quite satisfactory for them to be charged and set to zero at the time of issue to civil defense rescue workers and to be used continuously at intervals over a total period of several days without recharge; the final reading at the end of the incident then gives the total dose received by the wearer during the whole period. In this case, therefore, because the instrument has such good leakage characteristics, it can be, and is used, both as a counseling and a completion dosimeter, and logging of the reading and recharging of the instrument after each visit to the contaminated area is unnecessary.

The flash dosimeter covers a range of 25–800 r. As designed at present, they do not provide a means of continuous measurement over the whole range; rather they provide a means of assessing the dosage into the following groups: below 25 r, between 25–75 r, between 75–150 r, between 150–300 r, between 300–800 r, and above 800 r. Some are self-contained, i.e., direct-reading, and some require a separate "reader" for the assessment of dosage. All these flash dosimeters are essentially completion dosimeters according to Shurcliff's definition, irrespective of whether they are self-contained or not, because of their range of measurement and function.

DENIS TAYLOR
Atomic Energy Research Establishment
Harwell, England

* D. Taylor. Radiac instrumentation. *J. Sci. Instr.* (in press).

C^{14} Dating Service

DEAR SIRS:

Recently I investigated the possibility of getting some wood tested to determine its age by the carbon-14 method. I talked with one of the parties doing this work and found them a little reluctant to do such work, purely on the basis of curiosity as to the age of the materials being tested, due to the high cost of such tests.

Your magazine could do a service in bringing together people who are looking for material to test and people with material of scientific interest which they wish to have tested.

Possibly an inexpensive test could be made by putting the material to be tested in a pipe in a closed chamber, drawing a vacuum in the chamber, and then heating the material in the pipe by high-frequency induction heat. At the right stage of heat, a small trickle of oxygen would be allowed to pass through the material. Conditions would have to be such that all the oxygen was converted to CO or CO_2.

Probably a mixture of the two gases would result, and conditions should be such that absolutely no oxygen could dilute the gases. Possibly the introduction of a catalytic agent at the end of the pipe would insure this. The gases could then be placed under pressure with a counter inserted into the gases, and the count made. It would seem to me that this method would reduce background count to a minimum and be very inexpensive.

We are particularly interested in the practical and industrial applications

J. MANWARING
Radio Frequency Service
Medfield, Massachusetts

(*NUCLEONICS published a listing of available university C^{14} dating services in the August '52 issue, p. 21.*—Editor)

"Raw Materials" Expenditures

DEAR SIR:

From a study of the excellent graphic analysis of the AEC operations on page 97 of the June '52 NUCLEONICS, we note that the expenditures for raw materials (uranium ores and concentrates) for 1948, 1949, and 1950 averaged about $250,000,000.

In 1951 it made a startling jump to about $1,300,000,000. Now certainly there was no six-fold increase in the production of uranium ore in that year. Our conclusion is that there must have been a tremendous increase in the price paid to foreign producers. Can you throw any light on this matter?

Our interest is that of owners of two very important old patented groups of uranium mines—the Portugal and the Great Bear-Joachimsthal type.

ALBERT A. LEACH
Leach & Leach
Lordsburg, New Mexico

(*The "raw materials" expenditures you refer to are actually for "source and fissionable materials." There is a distinct difference between the two. We don't believe AEC has ever released specific cost figures relating to its "raw materials" expenditures. Instead, it has lumped such information under the heading of "source and fissionable materials." This latter category includes such things as the cost of building and operating feed-materials plants, gaseous-diffusion plants, and plutonium-producing reactors. Thus, the large figure for '51 includes the cost of the new plants at Paducah, Ky., and Savannah River, S. C.*—Editor)

IMPORTANT ANNOUNCEMENT

Of general interest to users of radioactive materials is the recent incorporation of the

COMMERCIAL PRODUCTS DIVISION

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as a division of

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This transfer is made solely to provide a more comprehensive and efficient service for our customers. No changes in personnel, established agents or business routine are involved.

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COMMERCIAL PRODUCTS DIVISION

P.O. Box 93—Ottawa, Canada

PRODUCTS AND MATERIALS

Liquid Counter

20th Century Electronics, Ltd., Dunbar Works, Dunbar St., W. Norwood, London, S. E. 27, England. The model M6 thin-walled liquid beta counter has a sampling jacket of stated capacity to give fixed-source geometry. An evaporated stainless iron cathode gives the counter an enhanced life and minimized photosensitivity compared to the original model. Plateau length is 200 volts; maximum slope is 0.06%/volt. The average operating voltage is 1,000. The temperature coefficient is 1 volt/° C from 20–50° C. Maximum counting rate is 20,000 cpm; deadtime is 120 μsec; stability at 10,000 cpm with fixed source is ±2%; the average shielded background count is 10 cpm. The counter has an expected life of 10^9 sec.

Glow-Transfer Counter

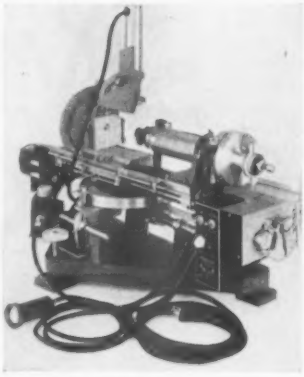
Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass. The self-indicating model 162 glow-transfer counter has a maximum capacity of 1,000,000 counts and maximum speed of 2,000 cps. It uses the decade Erickson-type ring counter tubes. Resetting is by manual push button or remote control. Input may be pulses or sine waves with 5-volt minimum amplitude from average value. Maximum rise time is about 10 msec; positive or negative input with minimum sensitivity is adjustable from 5 to 75 volts. Input impedance is 0.01 μf in series with 1.0 megohm.

Master-Slave Manipulator

Central Research Laboratories, Inc., Red Wing, Minn. The model 4 master-slave manipulator is a remote-control handling device designed to operate through a small opening in the ceiling of a totally enclosed space. Objects of 5–10 lbs which can be grasped with the thumb and two fingers of a human operator can be handled by the manipulator. The over-all height is 116½ in. The vertical range of the tongs is 37 in. The tongs may be rotated horizontally and vertically and have a twist motion.

Radioactive Current Source

Radiation Research Corp., P. O. Box 8126, West Palm Beach, Fla. The model B50 high-voltage battery utilizes the energy of the beta radiation from Sr^{90} to provide constant currents of $30–60 \times 10^{-12}$ ampere at zero voltage. From 1–6 kv can be obtained under no-load conditions. The battery has a linear charging rate to 100 volts. External radiation is less than 10 mr/hr. The operating temperature range is 0–40° C.



Goniometer Attachment

Research and Control Instruments Division, North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y. This goniometer, adapted to G-M counter operation, is designed as an attachment to Weissenberg cameras used in conjunction with the counting circuits and the recorder of the Philips X-ray spectrometer. The conversion of the Weissenberg equipment entails attaching a G-M counter tube, angular positioning mounts, and a mechanism for oscillating the crystal. The G-M tube may be tilted in the plane of the rotation axis of the crystal. The range of X-ray measurements is 0–140 degrees, covering 95% of all diffraction beams in this cone.

Omniometer

Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill. This radiation detector may be used with G-M, proportional, and scintillation counters. It has two high-voltage supplies providing overlapping ranges from 500 to 5,000 volts. If the detect-

ing element delivers ¼-volt pulses or higher, then access is direct to the scaling circuit; smaller pulses are fed into the amplifier input, and then to the scaler. The unit has scales of 64, 128, 256, and 512. The counting switch automatically actuates a built-in timer.

Decade Scaler

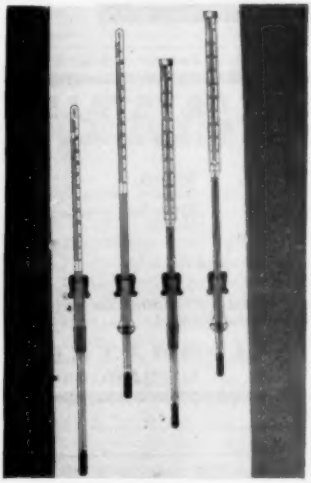
Nuclear Measurements Corp., 3339 Central Ave., Indianapolis, Indiana. The model DU1 decade scaling unit operates with scaling factors of 10, 100, and 1,000. Its resolution is 2 μsec. A negative input pulse of 140 volts with a rise time of less than 0.5 μsec is required; an output pulse of this character provides for cascade operation without buffer amplifiers. A positive 140-volt pulse is provided for driving a mechanical numeral register circuit. Power requirements are 6.3 volts at 1.8 amperes, and 300 volts at 45 ma.

Beta-Gamma Probe

Radioactive Products, Inc., 443 W. Congress, Detroit 26, Mich. The model D-5A beta-gamma probe, for use with the Samson alpha survey meter, contains a freon-filled ionization chamber and an electrometer pre-amplifier. A rotating 1,000-mg/cm² stainless-steel shield provides for beta discrimination. The probe extends the original Samson ranges of 0–500, 2,500, 12,500 alpha cpm (corresponding to 0–0.7, 3.5, 17.5 radium-gamma mr/hr) to 0–0.25, 1.25, 6.25, 25, 125, and 625 mr/hr.

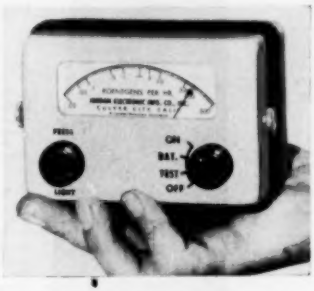
Metal-Walled G-M Tubes

H. W. Leighton Laboratories, 26 Herman St., Glen Ridge, N. J. These brass-walled G-M tubes are available with active lengths of 3, 10, 16, and 24 in., and with various fill-gases. Diameters range from ½ to 2 in. Exhaust tubes and insulation are kept within the diameter of the tube to permit close stacking. Starting voltages range from 870 to 1,000 volts. The 24-in. tube has a plateau length of 200 volts with a slope of <10%/100 volts; plateau lengths of the other tubes are 150–200 volts with a slope of <5%/100 volts. Recovery time is of the order of 25–35 μsec.



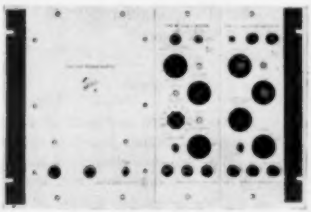
Adjustable-Stem Thermometer

Scientific Glass Apparatus Co., Inc., 100 Lakewood Terrace, Bloomfield, N. J. The Adjustatherm consists of a thermometer, having an etched scale against a yellow background or a milk-glass scale, fitted into a sleeve with either a standard taper or semi-ball joint. It is made in 6½- and 11½-in. stem lengths in ranges of 0–150° C, 0–250° C, and 0–360° C. Liquid and vapor temperatures may be obtained without dismantling the equipment by lifting and lowering the thermometer within the sleeve. It is claimed that a set of two will replace nine conventional thermometers.



Gamma-Radiation Detector

Jordan Electronic Mfg. Co., Inc., 9042 Culver Blvd., Culver City, Calif. Designed for civil defense use, the Radector γ-ray detector measures from 0.02 to 500 r/hr. Accuracy of the 2-lb ionization-chamber instrument is claimed to be within ±10%. Battery life in use is nearly equal to shelf life. No warm-up time is necessary and there is no indicator drift.



Waveform Generators

Tektronix, Inc., P. O. Box 831, Portland 7, Oregon. Pulse conditions of almost any degree of complexity can be provided by combining the type 160 regulated power supply with combinations of the type 161 pulse generator and the type 162 waveform generator. The type 161 rectangular pulse generator, triggered by a negative-going sawtooth or a positive pulse, gives three waveforms. The positive gate has an amplitude of 50 volts above ground, a duration of 10 μsec to 0.1 sec, and an impedance of 1,000 ohms. The positive pulse has a

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continuously variable amplitude of 0–50 volts, a duration of 10 μsec to 0.1 sec, a risetime of 0.5 μsec, and an impedance of 1,800 ohms. The negative pulse is identical with the positive except for polarity. The type 162 generator provides pulse, gate, and sawtooth waveforms. The positive pulse has an amplitude 50 volts above ground, a duration of 10 μsec to 0.2 sec, and a risetime of 1 μsec. The positive gate has an amplitude of 50 volts above ground and a duration of 10 μsec to 10 sec. The negative-going sawtooth has an amplitude decreasing uniformly with time from +150 to +20 volts and a duration of 10 μsec to 10 sec. Output impedance is constant at 1,000 ohms; triggering is by means of externally derived electrical pulse or gate.

Capacitance Standards

MacLeod and Hanopol, Inc., 10 Roland St., Charlestown 29, Mass. The model 388 set of secondary low-capacitance standards comprises two "T" networks, and three auxiliaries. The nominal network values are 0.075 and 7.5 μf; modified values of 0.001, 0.0075, and 0.75 μf can be obtained with the auxiliaries. All elements have Q of 200 or better and temperature coefficient of 0.05% per °C. True values are within 5% of the nominal values.

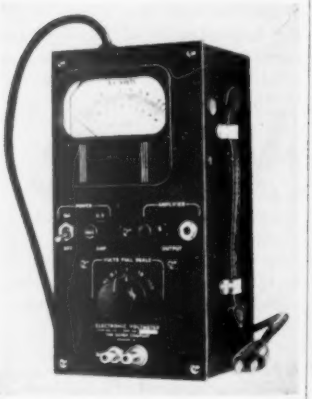
Cation Exchanger

Rohm and Haas Co., Resinous Products Division, Washington Sq., Philadelphia 5, Pa. Amberlite IR-112(H), a nuclear-sulfonic-acid-type ion exchanger, may be used for the adsorption of basic materials from aqueous and

non-aqueous solutions, recovery of metallic complexes and radioactive wastes, separation of rare earth metals and radioisotopes, and chromatographic separations. Exchange capacity is in the range of 1.2 to 1.5 milliequivalents per milliliter of resin. The resin, supplied as 0.5-mm beads, is resistant to attrition, *p*H change, and high temperature, and is normally unaffected by strong acids and bases, oxidizing and reducing agents, organic solvents, chlorine, and freezing.

Power Supply

Perkin Engineering Corp., 345 Kansas St., El Segundo, Calif. The model M30 regulated d-c power supply provides a continuously variable 0–325-volt output. The unit has a d-c rating of 150 ma and is equipped with an a-c output of 6.3 volts, 6 amperes. Regulation is within ½% from 30–325 volts from no load to full load; ripple is less than 2 mv.



Voltmeter

Daven Co., 191 Central Ave., Newark 4, N. J. The type 170A portable voltmeter has separate amplifier and power supply subassemblies. The two sections are electrostatically and magnetically shielded from each other and from external fields. The voltmeter measures a-c sinusoidal voltages over a range of 10–250,000 cycles and 0.001–100 volts within ±2%. The meter

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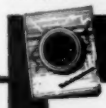

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Lovins Engineering Co., 8203 Cedar St., Silver Spring, Md. A wet-processing unit is available for handling up to 200 film badges every 15 min. Special fixtures for processing 5 × 7-in. and 4 × 5-in. films, or up to thirty 35-mm rolls can be supplied. The unit includes signalling timers, racks, tanks, washer, and a constant-temperature water feed operating at ±14° F; drier is optional. All power is obtained from the water mains; plumbing connections are standard and pressure regulators are included. A hydraulic motor supplies agitation.

Screen Room

Lindgren Screen Room, Dept. L., 4515 N. Ravenswood Ave., Chicago 40, Ill. These portable radio silence test chambers, for test and evaluation of electronic equipment, have a double-screen design in which the screens are electrically insulated from each other. Electrical noise or interference which penetrates the first screen is said to be attenuated to such a degree that it encounters a practically impenetrable barrier in the second screen. The panels, constructed of pine, come in standard dimensions of 31 × 91 in. Entrance and access doors can be placed where needed. The inner and outer copper screens are 1⅝ in. apart. All hardware is copper plated. The floor is ⅝-in. plywood.

Diffusion Pump

Kahl Scientific Instrument Corp., P. O. Box 1166, El Cajon, Calif. The No. 1625 high-vacuum, mercury-type diffusion pump creates a vacuum of 10^{-6} mm. A freeze-out trap condenses all vapors and prevents their flowing into the system. Mercury pumps do not have the critical temperature range required for oil diffusion pumps.

Resistors

Instrument Resistors Co., Commerce Ave., Union, N. J. These resistors, designed to withstand ambient temperatures in excess of 235° C, are claimed to have a resistance variation of less than 0.2% from −55 to +125° C. Resistances to 25,000 ohms and power ratings to 6 watts can be supplied. Standard tolerances are 1%; tolerances to 0.1% may be ordered.

INDUSTRY NOTES

▶**Marion Electrical Instrument Co.,** Manchester, N. H., has added two new members to its home office staff. John D. McLellan becomes plant manager in charge of manufacturing operations; Herbert L. Schachat is manager of government sales.

▶**Furst Electronics** has moved to a new location at 3322 W. Lawrence Ave., Chicago, Ill.

▶**Eldorado Mining and Refining, Ltd.,** Ottawa, Ontario, Canada, has announced the transfer of its Commercial Products Division to Atomic Energy of Canada, Ltd. The division will still be located in Ottawa; personnel and products handled will remain the same. Its new address is: Commercial Products Division, Atomic Energy of Canada, Ltd., P. O.

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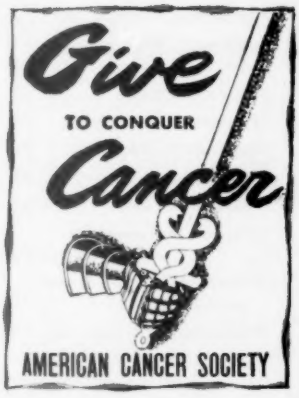

Box 93, Ottawa, Canada. Eldorado will continue its production and marketing of uranium.

▶**Beckman Instruments, Inc.,** South Pasadena, Calif., has purchased the business and assets of Berkeley Scientific Corp. of Richmond, Calif. Operations will continue as the Berkeley Scientific Division of Beckman Instruments, Inc. No changes in personnel are contemplated. W. K. Rosenberry, president of Berkeley Scientific, becomes a vice president of Beckman and will remain in charge of operations at the Richmond plant.

▶**National Research Corporation,** 70 Memorial Dr., Cambridge, Mass., has occupied a new 50,000 square foot plant in Newton, Mass., representing a 100% increase in floor space. In this $600,000 plant, the equipment division, directed by H. C. Weingartner, will produce process equipment for use in the chemical, metallurgical, electronic, and coating industries.

LITERATURE AVAILABLE

Electronic instruments. Catalog describes line of electronic and nucleonic apparatus. *Labgear (Cambridge) Ltd., Willow Place, Cambridge, England.*

Infra-red analyzer. Bulletin 0705-1 describes this infra-red gas and liquid analyzer designed for rapid, automatic analysis of fluid mixtures. *Mine Safety Appliances Co., Braddock, Thomas and Meade Streets, Pittsburgh 8, Pa.*

Temperature controls. Catalog G17 gives data on the line of temperature controls. *Burling Instrument Co., 5 Vose Ave., South Orange, N. J.*

Sodium iodide solutions. This pamphlet furnishes information on the physiological use of NaI^{131} solutions. *Abbott Laboratories, North Chicago, Ill.*

Radioactivity instrumentation. This catalog lists the complete line of laboratory radioactivity instruments. *Nucleonic Co. of America, 497 Union St., Brooklyn 31, N. Y.*

Universal breadboard. The brochure describes a newly designed breadboard. *Electro Manufacturer's Corp., 2105 Ludlow St., Philadelphia 3, Pa.*

Film badge service. This booklet describes the operation of a weekly film badge service for personnel exposure. *Tracerlab, Inc., 130 High St., Boston 10, Mass.*

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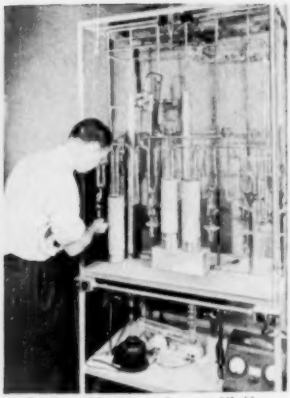

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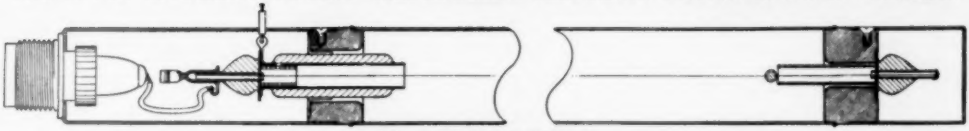

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